AFRL-ML-TY-TR-2000-4521

ADVANCED FIRE PROTECTION DELUGE SYSTEM (AFPDS) PHASE II REPORT

S.P. WELLS
V. CARR
K.S. COZART

U.S. ARMY DEFENSE AMMUNITION LOGISTICS ACTIVITY
(AMSTA-AR-AL)
PICATINNY ARSENAL NJ

Approved for Public Release; Distribution Unlimited

AIR FORCE RESEARCH LABORATORY
MATERIALS & MANUFACTURING DIRECTORATE
AIRBASE & ENVIRONMENTAL TECHNOLOGY DIVISION
TYNDALL AFB FL 32403-5323

PREFACE

This report was prepared by the Air Force Research Laboratory (AFRL) Airbase Technology Branch, Tyndall Air Force Base, Florida 32403. An electronic copy of the report can be obtained on CD-ROM by contacting AFRL. The CD-ROM also contains the data used to create the spectral analysis charts located in the appendix and a video of the project. The charts in the appendix are only a small sample of the actual data taken during testing, actual data is on the CD-ROM.

Mr. Robert Rossi, AMSTA-AR-AL, was the Project Manager. Mr. Robert Loyd, AMSIO-SF was the Technical Advisor. This test program was completed in support of AMSTA-AR-AL. This report presents the results of the Advanced Fire Protection Deluge System study.

This report has been reviewed and is approved.

JUAN A. VITALI
Chief, Fire Research Group
AFRL/MLQC

RICHARD N. VICKERS
Chief, Airbase Technology Branch
AFRL/MLQC

RANDY L. GROSS, Colonel, USAF, BSC
Chief, Air Expeditionary Forces Technologies Division

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	April 2000	Final Report June 96 - December 98

4. TITLE AND SUBTITLE
Advanced Fire Protection Deluge System (AFPDS)
Phase II Report

5. FUNDING NUMBER

6. AUTHORS
S.P. Wells, V. Carr, K.S. Cozart

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Air Force Research Laboratory (AFRL/MLQF)
Materials & Manufacturing Directorate
Air Expeditionary Forces Technologies Division
Tyndall AFB FL 32403-5323

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Defense Ammunition Logistics Activity
(AMSTA-AR-AL)
Picatinny Arsenal, NJ

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
AFRL-ML-TY-TR-2000-4521

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for Public Release; Distribution Unlimited

12b. DISTRIBUTION CODE
A

13. ABSTRACT *(Maximum 200 words)*
For several years munitions plants and arsenals have been plagued by deflagrations of pyrotechnic material that have caused loss of life, serious injuries, and extensive property damage. These problems have been caused by detection and suppression systems that are too slow for current applications or have been hampered by false alarm stimuli. As a result, the Army teamed with the Air Force Fire Research Branch at Tyndall AFB. This team effort led to the approval and funding of a research and development project to devise a better fire detection and suppression system for the Army facilities. In Phase I tests, this system consistently suppressed burning energetic material (less than one pound) in less than 30 milliseconds after flame detection from a nozzle height of 36 inches. This system includes strategically placed explosively actuated water suppression devices and improved optical flame detectors that decrease the possibility of false alarms with no significant increase in response time. This Phase II effort evaluated the AFPDS in an operational environment, conducted suppression tests of several materials not tested in Phase I, and measured the spectral emission characteristics of several pyrotechnics and propellants to provide data for optimizing the response of high-speed optical flame detectors.

14. SUBJECT TERMS
high-speed deluge, spectral analysis, deluge system, fire protection

15. NUMBER OF PAGES
106

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500
Computer Generated
STANDARD FORM 298 (Rev 2-89)
Prescribed by ANSI Std 239-18
298-102

EXECUTIVE SUMMARY

A. OBJECTIVE

This Phase II study had three main objectives: to evaluate the Advanced Fire Protection Deluge System (AFPDS), developed and tested in Phase I, in an operational environment; to evaluate the system against pyrotechnic materials not tested in Phase I in quantities up to two pounds (908g); and to measure the spectral emissions of fires involving these munitions materials for use in flame detector optimization. The accomplishment of these three objectives will further enhance the confidence in this system which performed superbly in Phase I testing.

B. BACKGROUND

For several years munitions plants and arsenals have been plagued by deflagrations of pyrotechnic material that have caused loss of life, serious injuries, and extensive property damage. The private sector has also suffered injuries, deaths and property damage. Much of this has been caused by detection and suppression systems that are too slow for current applications or have been hampered by serious false alarm stimuli. Between 1988 and 1992 alone, the U.S. Army Industrial Operations Command (formerly U.S. Army Armament, Munitions and Chemical Command) suffered almost $10 million dollars in losses including 3 deaths and nine serious injuries. As a result, the Army decided to seek a resolution of the problem by teaming with the U.S. Air Force Fire Research Branch at Tyndall AFB who possessed extensive knowledge of fire suppression and mitigation techniques. The first accomplishment of this team effort provided a written synopsis of problems in a September 1993 report that eventually led to the approval and funding of a new research and development project to devise a better fire detection and suppression system for the plants and arsenals.

After demonstrating a concept and receiving funds, the Air Force Research Laboratory (AFRL/MLQC) conducted a Phase I development program for the U.S. Army Defense Ammunition Logistics Activity which has demonstrated for the first time an effective and reliable suppression system using water as an agent. In the Phase I tests, this system has consistently suppressed burning energetic material (less than one pound) in less than 30 milliseconds after flame detection from a nozzle height of 36 inches. This system includes strategically placed explosively actuated water suppression devices and improved optical flame detectors that decrease the possibility of false alarms with no significant increase in response time. Phase I of this project is documented in the *Advanced Fire Protection Deluge System Phase I Report*[1]. A complete recap of the Phase I results is included in AFRL-ML-TY-1998-4526 which can be ordered as follows: GOV Agency – Phone: (800) 225-3842 or on the internet: http://www.dtic.mil/dtic/docorderform.html. All others – Phone: (800) 533-NTIS or on the internet : http://www.fedworld.gov.

C. APPROACH

A primary objective of this Phase II effort was to evaluate the AFPDS in an operational environment. It was believed that the highly successful tests conducted in Phase I could be applied to real-life work situations at the plants and arsenals involving such processes as screening, sawing, drying, pressing, extrusion, and pouring. Working with the U.S. Army Industrial Operations Command safety office, a powder charging machine from the Lake City Army Ammunition Plant (AAP) was shipped to Tyndall AFB for “real-world” testing. The powder charging machine is used in an assembly line process to load small amounts of pyrotechnic materials into projectiles. The results of those tests, which are contained in this report, have clearly demonstrated that the AFPDS can protect a worker from serious injury including burns and thermal effects of a deflagration. The system can substantially mitigate damage to the surrounding plant components.

As materials used at different plants vary substantially from location to location, a second objective of Phase II testing was to conduct burn tests of several materials not tested in Phase I. These tests were conducted in an apparatus used to simulate an actual workstation. The AFPDS was tested for suppression of materials in quantities of ¼ pound (113g) up to two pounds (908g). It should be noted that the test facility had a two-pound limit, for hazard class 1.1, of munitions burn samples because of current certification of the building for that amount. Additional tests that will eventually lead to simulation of a mixing bowl operation (up to 25 pounds) will be conducted in a sister AFRL/MLQC facility on Tyndall AFB.

Another key objective of the Phase II project was to measure the spectral emission characteristics of several pyrotechnics and propellants. At the time of the commencement of the Phase I study, this had never been accomplished for materials being used in military and commercial plants and arsenals. It was believed that by measuring such data from the pyrotechnic and propellant burns that detector manufacturers could use the results to adjust the measurement parameters of their detectors to recognize material burns the detector might miss. They could also use the data to optimize detectors for better performance. Spectral measurements under Phase II of this study were accomplished with an Oriel Instaspec IV UV spectrometer and a Midac Fourier Transform Infrared (FTIR) Spectrometer, model # M2400-ZNSE. A total of 23 munitions materials were tested for spectral emissions data that is summarized in Section III of this report. This spectral data is also available on a CD-ROM.

It should be noted that the three new detectors (Spectrex UV/IR, Dual Spectrum IR/IR, and Fire Sentry UV/VIS/IR) as well as the Detector Electronics UV model all performed exceptionally well against most of the materials tested in the Phase I and Phase II programs which included over 200 fires. Although the question has been resolved concerning each detector’s capability to see various material, it is recommended that further testing of spectral emission signatures be continued for new materials tested. Any improvement in seeing the initial burn of these materials in their incipient state is desirable because of the extremely fast burning rate of several materials and their capability to produce destructive explosions.

D. RESULTS

1. Each of the three new pyrotechnics and four new propellants in quantities ¼ to two pounds (113 to 908g) and three high explosive material compounds in quantities of ¼ pound (113g), burned without detonation when suppressed with the AFPDS.

2. The AFPDS was able to detect and successfully extinguish each sample of these new burning materials for every test burn accomplished in a simulated workstation.

3. As in Phase I, each detector performed differently with each material but was highly successful in operating the AFPDS in a manner to suppress/extinguish a munitions fire. However, some detectors were better than others for a particular application/material (Note: see results in Section III).

4. As in Phase I, the sphere water provided enough cooling to control and extinguish the new burning munitions samples tested in the workstation apparatus, with the exception of two tests (see conclusion #5 below). Very little testing was accomplished with follow-on water in that the flames were extinguished in practically every test before the follow-on water would have had any effect. However, it is recommended that any existing deluge water supply system, installed in a plant or arsenal, be left in place as long as it is properly functioning. For example, an in-place heat activated device (HAD) could be modified with solenoid nozzles to backup the AFPDS. This may not be possible in some situations such as using the AFPDS in a portable configuration.

E. CONCLUSIONS

1. The AFPDS can be easily installed to protect people and equipment in real life working situations as found at ammunition plants and arsenals. This was demonstrated by installing the system in a powder charging machine as used at the Lake City AAP. The installation of the AFPDS, when completed, will provide substantial improvements over that protection now provided by current suppression systems at Lake City AAP.

2. The AFPDS can be modified to improve the performance of most of the currently installed high-speed suppression systems installed in munitions plants.

3. Materials, such as RS-41, whose burn rates can vary dramatically, should be protected with two or more separate detectors, one that protects for the case of slow flame propagation and one that protects for fast flame propagation. Currently, in many installations, two identical detectors are used to monitor the same area for redundancy. This unique idea provides for two separate detectors to improve system performance and to also assure redundancy.

This particular material, RS-41, when burned in the powder charging machine, would propagate in one of two ways: 1) very fast or, 2) slow at first, then very fast. In the first case, the fastest detector available would be needed to activate the deluge system. The second case is more complicated. Test results show that the fastest detectors for fast propagating events can be the slowest detectors for slow propagating events. This phenomenon is due to the detector design and logic. In the case of a slow growing fire, the objective is to extinguish the flame before the propagation rate significantly increases. The detector of choice here is the one that detects the slow growing fires the fastest. A combination of the fastest detector for fast growing events and the fastest detector for slow growing events should be used to activate the suppression system in areas where highly energetic materials like these are used. This report and the Phase I report have detection times for each material tested and for each detector.

For RS-41 a good detector combination to provide protection would be the Spectrex detector and the Fire Sentry detector evaluated in this test series. Spectrex detects the fast growing events the fastest and Fire Sentry detects the slowest growing events the fastest. (Note: Testing proved that for redundancy, the Fire Sentry will detect a fast growing event as a backup to the Spectrex, and the Spectrex will detect a slow growing event as a backup to the Fire Sentry.)

4.   All of the Phase II materials were successfully detected and extinguished in the workstation tests. Six of these materials were tested in two pounds (908g) quantities. Most of these tests were conducted with only the AFPDS sphere extinguisher and no follow-on water.

5.   Five Phase I materials were also tested with two pounds (908g) of material using the AFPDS with no follow-on water. All of these materials were successfully extinguished, however in two of the three M206 tests conducted with two pounds of material, the water from the sphere was insufficient to completely suppress the material, although there was a significant amount of unburned material after the test. In this case the follow-on water would have aided in achieving suppression. Although the solenoid activated follow-on water was not needed in all but two of our tests, it is recommended that this system (solenoid activated follow-on water) be installed for most applications to provide for a longer discharge of water which will also meet NFPA 15[2] requirements. For example, an in-place heat activated device (HAD) could be modified with solenoid nozzles to backup the AFPDS.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF GRAPHS

APPENDIX

LIST OF GRAPHS

LIST OF GRAPHS

DEFINITIONS

Contained Flame Time. The time that suppression water surrounds the flame preventing further flame propagation.

Controller Signal Output. The instant that an electronic controller system issues a suppression discharge signal.

Detectable Event. The first indication of a visible fireball generated by the ignited material, as viewed on the high-speed camera, that should be "seen" by a flame detector.

Detection Response Time (Flame Detection Time). The instant that an optical flame detector issues a fire alarm signal. Detection response time is measured from the detectable event.

Event Initiation. Ignition time of the electric match that started the event.

False Activation. Unwanted discharge of a suppression deluge system caused by a mechanical or electrical malfunction or by a detection system false alarm.

False Alarm. An alarm signal issued by a optical flame detector when no flame is present. A false alarm is most often caused by radiation emissions in the same spectral band that the flame detector uses to detect fires.

Flame Extinguishment. The time from the detectable event until the visible flame is no longer present, as viewed on the high speed camera.

Follow-On Water System. Nozzle pressurized water, solenoid activated, which provides additional cooling and extinguishment during and after sphere discharge.

Nozzle Discharge Time. The instant that water exits the nozzle

Nozzle Response Time. The time from Controller Signal Output until water discharge.

Sphere Discharge Time. The instant that water exits the high rate discharge sphere.

Sphere Response Time. The time from Controller Signal Output until sphere discharge.

Water on Flame. The time from the detectable event until the water discharged from the suppression system reaches the visible flame.

SECTION I

INTRODUCTION

A. OBJECTIVE

This Phase II study had three main objectives: to evaluate the Advanced Fire Protection Deluge System (AFPDS), developed and tested in Phase I, in an operational environment; to evaluate the system against pyrotechnic materials not tested in Phase I in quantities up to two pounds (908g); and to measure the spectral emissions of fires involving these munitions materials for use in flame detector optimization. The accomplishment of these three objectives will further enhance the confidence in this system which performed superbly in Phase I testing.

B. BACKGROUND

For several years munitions plants and arsenals have been plagued by deflagrations of pyrotechnic material that have caused loss of life, serious injuries, and extensive property damage. The private sector has also suffered injuries, deaths and property damage. Much of this has been caused by detection and suppression systems that are too slow for current applications or have been hampered by serious false alarm stimuli. Between 1988 and 1992 alone, the U.S. Army Industrial Operations Command (formerly U.S. Army Armament, Munitions and Chemical Command) suffered almost $10 million dollars in losses including 3 deaths and nine serious injuries. As a result, the Army decided to seek a resolution of the problem by teaming with the U.S. Air Force Fire Research Branch at Tyndall AFB who possessed extensive knowledge of fire suppression and mitigation techniques. The first accomplishment of this team effort provided a written synopsis of problems in a September 1993 report that eventually led to the approval and funding of a new research and development project to devise a better fire detection and suppression system for the plants and arsenals.

After demonstrating a concept and receiving funds, the Air Force Research Laboratory (AFRL/MLQC) conducted a Phase I development program for the U.S. Army Defense Ammunition Logistics Activity which has demonstrated for the first time an effective and reliable suppression system using water as an agent. In the Phase I tests, this system has consistently suppressed burning energetic material (less than one pound) in less than 30 milliseconds after flame detection from a nozzle height of 36 inches. This system includes strategically placed explosively actuated water suppression devices and improved optical flame detectors that decrease the possibility of false alarms with no significant increase in response time. Phase I of this project is documented in the *Advanced Fire Protection Deluge System Phase I Report*[1]. A complete recap of the Phase I results is included in AFRL-ML-TY-1998-4526 which can be ordered as follows: GOV Agency – Phone: (800) 225-3842 or on the internet: http://www.dtic.mil/dtic/docorderform.html. All others – Phone: (800) 533-NTIS or on the internet : http://www.fedworld.gov.

C. APPROACH

A primary objective of this Phase II effort was to evaluate the AFPDS in an operational environment. It was believed that the highly successful tests conducted in Phase I could be applied to real-life work situations at the plants and arsenals involving such processes as screening, sawing, drying, pressing, extrusion, and pouring. Working with the U.S. Army Industrial Operations Command safety office, a powder charging machine from the Lake City Army Ammunition Plant (AAP) was shipped to Tyndall AFB for “real-world” testing. The powder charging machine is used in an assembly line process to load small amounts of pyrotechnic materials into projectiles. The results of those tests, which are contained in this report, have clearly demonstrated that the AFPDS can protect a worker from serious injury including burns and thermal effects of a deflagration. The system can substantially mitigate damage to the surrounding plant components.

As materials used at different plants vary substantially from location to location, a second objective of Phase II testing was to conduct burn tests of several materials not tested in Phase I. These tests were conducted in an apparatus used to simulate an actual workstation. The AFPDS was tested for suppression of materials in quantities of ¼ pound (113g) up to two pounds (908g). It should be noted that the test facility had a two-pound limit, for hazard class 1.1, of munitions burn samples because of current certification of the building for that amount. Additional tests that will eventually lead to simulation of a mixing bowl operation (up to 25 pounds) will be conducted in a sister AFRL/MLQC facility on Tyndall AFB.

Another key objective of the Phase II project was to measure the spectral emission characteristics of several pyrotechnics and propellants. At the time of the commencement of the Phase I study, this had never been accomplished for materials being used in military and commercial plants and arsenals. It was believed that by measuring such data from the pyrotechnic and propellant burns that detector manufacturers could use the results to adjust the measurement parameters of their detectors to recognize material burns the detector might miss. They could also use the data to optimize detectors for better performance. Spectral measurements under Phase II of this study were accomplished with an Oriel Instaspec IV UV spectrometer and a Midac Fourier Transform Infrared (FTIR) Spectrometer, model # M2400-ZNSE. A total of 23 munitions materials were tested for spectral emissions data that is summarized in Section III of this report. This spectral data is also available on a CD-ROM.

It should be noted that the three new detectors (Spectrex UV/IR, Dual Spectrum IR/IR, and Fire Sentry UV/VIS/IR) as well as the Detector Electronics UV model all performed exceptionally well against most of the materials tested in the Phase I and Phase II programs which included over 200 fires. Although the question has been resolved concerning each detector’s capability to see various material, it is recommended that further testing of spectral emission signatures be continued for new materials tested. Any improvement in seeing the initial burn of these materials in their incipient state is desirable because of the extremely fast burning rate of several materials and their capability to produce destructive explosions.

D. MATERIALS TESTED

The following munitions materials were tested during this Phase II effort. The first ten materials were tested for suppression with the AFPDS in the workstation. Three of these materials were tested in the Lake City AAP powder charging machine. Material numbers 11-17 are Phase I materials which were tested on the floor, 72 inches away from the detectors and the AFPDS. Some of these Phase I materials were also evaluated in workstation tests. The additional pyrotechnic materials (numbers 18-25) are propellants which, along with the pyrotechnic materials, were analyzed for spectral emissions when burning. No suppression tests were conducted with the additional pyrotechnic materials (numbers 18-25).

(1) **Incendiary Composition, RS-40** Magnesium Aluminum Alloy (49.5%), Ammonium Nitrate (24%), Aerocell (0.5%), Barium Nitrate (24%), and Calcium Resinate Fuzed (2%). Hazard Classification: **Class 1.1G**

(2) **Incendiary Composition, RS-41** Magnesium Aluminum Alloy (48%), Calcium Resinate Fuzed (2%) and Potassium Perchlorate (50%). Hazard Classification: **Class 1.1G**

(3) **Dim Tracer Composition, R-440** Barium Peroxide (41.5%), Strontium Peroxide (41.5%), Calcium Resinate Fuzed (10%) and Magnesium Carbonate (8%). HCSDS 1608. Hazard Classification: **Class 1.1G**

(4) **Propellant, Hy-Skor 700X** Nitrocellulose and Nitroglycerin. HCSDS 1628. Hazard Classification: **Class 1.1C**

(5) **Propellant, M14** Nitrocellulose (90%), Dinitrothene (8%), Dibutylphalate (2%), and Diphenylamine (1%). HCSDS 1912. Hazard Classification: **Class 1.3C**

(6) **Propellant, JA-2** Nitrocellulose (59.5%), Diethylene Glycol Dinitrate (24.8%), Nitroglycerin (14.9%), Magnesium Oxide (0.04-0.05%), N-Methyl-N'-N'Diphenylurea (0.7%), and Graphite (0.24-0.25%). HCSDS 1258. Hazard Classification: **Class 1.3C**

(7) **Propellant, LKL** Nitrocellulose (93.6%), Dinitrotoluene (3%), Potassium Sulfate (1.4%), Dibutylphthalata (1%), Diphenylamine (1%) and Graphite (0.2%). HCSDS 1805. Hazard Classification: **Class 1.3C**

(8) **Explosive Molding Powder, LX-17-0** Chemical Name: 2,4,6-trinitro-1,3,5-benzenetriamine. Composition: TATB (92.5%) and Kel-F800 (7.5%). Hazard Classification: **Class 1.1D**

(9) **Explosive Molding Powder, PBX-9501** Composition: HMX (95%), Estane (2.5%), BIS (2, 2-Dinitropropyl)Acetal (BDNPA) (1.25%), and %), BIS (2, 2-Dinitropropyl)Formal(ADNPF) (1.25%). HCSDS 1006. Hazard Classification: **Class 1.1D**

(10) **Explosive Molding Powder, PBX-9502** Composition: TATB (95%) and Kel-F800 (5%). Hazard Classification: **Class 1.1D**

Phase I Materials

(11) **MK 25 Starter Composition** Cupric oxide (30%), Lead Dioxide (80%), and Powdered Silicon (50%) for MK 25 Marine Locate Marker. HCSDS 40180. Hazard Classification: **Class 1.3G**

(12) **Delay Composition, Red Lead** Lead Oxide Tetra Red (80%), Silicon (16%), and Copolymer (4%) MK875 Flare Simulator. HCSDS 41192. Hazard Classification: **Class 1.3G**

(13) **Smoke Composition, Yellow** Dye - Solvent Yellow 33 (42%), Magnesium Carbonate (21%), Potassium Chlorate (22%), and sugar (15%) for M18 Hand Grenade, Smoke Yellow. HCSDS 20056. Hazard Classification: **Class 1.3G**

(14) **Smoke Composition, Green** Dye - Solvent Yellow 33 (12.5), Dye - Solvent Green 3 (29.5%), Magnesium Carbonate (17%), Potassium Chlorate (24.5%), and sugar (16.5%) for M18 Hand Grenade, Smoke Green. HCSDS 20055. Hazard Classification: **Class 1.3G**

(15) **M206 IR Flare Composition** Magnesium, Polytetrafluorethylene (TFE-Fluorocarbon), Hycar Dry Rubber, and Acetone and/or Magnesium (62-75%). Fluorollostomer (5-18%), and TFE (7-43%) for M206 IR Counter Measures Flare. HCSDS 1106 and 1107. Hazard Classification: **Class 1.3G**

(16) **First Fire Mixture (Type I)** Barium Nitrate (50%), Tetranitrocarbazole (10%), Zirconim Hydride (15%), Silicon (20%), Resin (2%). HCSDS 40129. Hazard Classification: **Class 1.3G**

(17) **M125 Illuminate Composition** Magnesium Type IV 30/50 (33%), Barium Nitrate/Class 6 (46%), Polyvinyl Chloride (16%), and Laminac (9%) for the M125 Signal, Illumination, Ground Star Cluster. HCSDS 1478. Hazard Classification: **Class 1.1D**

Additional Pyrotechnic Materials

(18) **UTP 19048 Solid Rocket Propellant** Ammonium Perchlorate (84%), R-45 Polymer (14%), Aluminum (2%), FE 203 (<1%)

(19) **UTP 19,360B Solid Rocket Propellant** Ammonium Perchlorate (68%), Aluminum (18%), HTPB (13%), Isophorone Disocyanate (<1%), HX-752 (<1%), Protech (0.1%), Ferricoxide (0.01%)

(20) **UTP-24745D Solid Rocket Propellant** Ammonium Perchlorate (69%), Aluminum (20%), Inert Meterials (10%), FE 203 (<1%)

(21) **UTP-25201C Solid Rocket Propellant** AP 200 MICRON (49%), AP 15 MICRON (19%), Aluminum Powder (20%), R-45 (polybutadiene polymer) (9%), IDP (Isodecyl Pelargonate) (2%), Iron Oxide (1%), HX-752 (<1%), Protech 3105 (0.1%), TPB (0.005%)

(22) **UTP-3001B Solid Rocket Propellant** AP 200 MICRON (49%), AP 9 MICRON (19%), Aluminum (16%), MNA (14%), DOA (2%), FE 203 (<1%)

(23) **UTP-31,500 Solid Rocket Propellant** Solids (Alum./AP/HTPB Binder) (87%), Curative Agents, Binders (13%)

(24) **$BKNO_3$ Ignition Material** Boron (12-25%), Potassium Nitrate (70-85%)

(25) **MTV** Magnesium (54%), Polytetrafluoroethylene (30%), Synthetic Rubber, Fluoro (16%)

SECTION II

TEST PROTOCOL

The Phase II objectives were to evaluate the AFPDS in an operational environment, to conduct burn tests of several materials not tested in Phase I and to measure the spectral emission characteristics of several pyrotechnics and propellants. To meet these objectives, pyrotechnic and propellant materials were evaluated for suppression in a workstation setup. In addition, Phase I materials were tested up to 72 inches away from the suppression nozzles and flame detectors in the AFPDS test facility. Powder charging machine tests were conducted in operational enclosures from Lake City AAP with the RS-41, RS-40 and R-440 materials. Spectral analysis was conducted with 23 materials from Phase I and Phase II.

A. DELUGE SYSTEM

In Phase I of this project, a prototype system was built using dual-band IR, combination UV/IR, and UV optical fire detectors; a fast response (<< 1ms) control panel; high speed pressurized water discharged from 10 liter and 30 liter high-rate discharge spheres; and follow-on pressurized water from standard nozzles as found in existing plant and arsenal systems.

The high-rate discharge sphere extinguishers were filled with the appropriate amount of water and charged to 500 psi for most tests. Figure 1, below, shows an animated cut-away of the sphere filled with water and charged with nitrogen (shown in green at the top of the extinguisher). Figure 2 depicts the system after detecting a flame when the control panel activates an internal explosive squib. The sudden increase in pressure opens a burst disk located on the bottom of the assembly to discharge water in less than four milliseconds (see Figure 3). Because the exploding actuator (contained within the sphere) produces an internal pressure within the sphere, the nitrogen is further pressurized and creates a spring effect discharging the water at about twice the static pressure. Thus, when a sphere is pressurized to 500 psi, the water is expelled at about 1000 psi of pressure, per the manufacturer. A screen and spreader, located in the nozzle, break the water into small, atomized particles, assuring even distribution and collecting the residual fragments of the squib. This atomized water provides an outstanding cooling

Figure 1
Cut-away of Charged Sphere

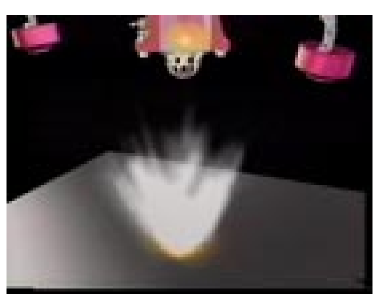


Figure 2
Activation of Internal Explosive Squib

Figure 3
Water Discharge on Flame

effect and is safe for workers in the general area. Three nozzles were used during tests, a 160° pattern nozzle, a 180° pattern nozzle, and a 90° pattern nozzle. The 180° and 90° pattern nozzles were designed and machined in the AFRL machine shop. Due to the nozzle velocity of the extinguisher water as it leaves the sphere, however, workers should remain two feet away from the sphere nozzle. This distance was arrived at by inadvertent discharges of the system during installation and testing.

The follow-on water system was comprised of standard high-speed solenoid activated valves (Pyrotech International manufactured), common at many plants and arsenals. The system pressure for the follow-on water was 200 psi. As mentioned before, the follow-on water was not used in a majority of the Phase II tests. It was observed in Phase I that in most cases the fire was extinguished before the follow-on system had an effect on the event.

The system was built and installed in the Advanced Fire Protection Deluge System (AFPDS) Test Facility at Tyndall AFB, FL that is capable of supporting explosive testing. Formal testing commenced in January 1996 and over 100 “burns” were accomplished in Phase I with 8 different pyrotechnic materials obtained from the U.S. Army plants and arsenal assembly lines that will eventually use this system. These tests included samples ranging in size from 1/4 lb (113g) to 1/2 lb (227g).

In this Phase II effort, an additional 10 pyrotechnic and propellant materials were evaluated with this suppression system, including sample quantities up to two pounds. The AFPDS was also modified for conducting tests of the Lake City AAP powder charging machine. These modifications included changing the angle of water spray exiting the nozzle, adding water-filled plumbing with blow-off plugs below the burst disk to better direct the spray pattern, and adding a deluge valve to a 3” elbow attached to the bottom of the sphere. The latter configuration consisted of moving the burst disk and explosive squib from the sphere nozzle to the deluge valve, filling the sphere and elbow with water and pressurizing them to 500 psi.

B. ULTRA HIGH-SPEED DETECTORS

The ultra high-speed detectors evaluated in the Phase I AFPDS study, were also used in this Phase II study. The data collection system was set up to determine the reaction time for each individual detector while allowing for alarming the control panel with a single detector or with the first unit to respond out of a predetermined set of detectors. Figure 4 shows the high-speed detectors along with the high-rate discharge sphere.

The detectors evaluated are as follows:

Detector Electronics Dual Spectrum	PM-5SX, IR/IR
Fire Sentry	SS2-A, UV/VIS/IR
Spectrex	620002 (SAFE), UV/IR
Detector Electronics, UV detector	R7303/C7050B UV

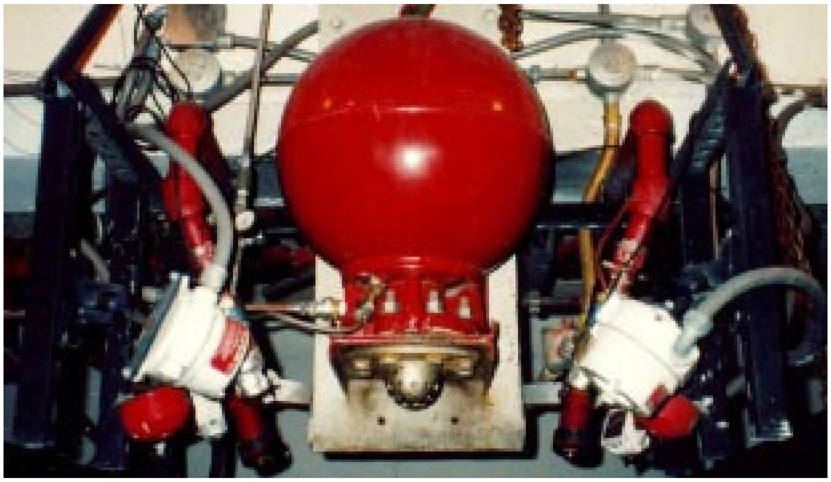


Figure 4
High-Speed Detectors and High-rate Discharge Sphere

The capability of these detectors to react to flames and activate the AFPDS suppression system was proven again and again in Phase I and Phase II testing. Detection times have been recorded as fast as two milliseconds after the detectable event. The false alarm immunity of these detectors was also proven in Phase I. When designing a suppression system, there are three major points to consider before choosing a detector.

1. The location and activities present where the system will be installed (i.e. what kind of fire is expected, how fast does the material burn, are people present, will the fire propagate).

2. The detector's response time to the material being protected. This should include the fastest response times, slowest response times and average response times. These should be evaluated based on required suppression requirements before making a decision on a detector.

3. The detector's response when presented false alarm sources. The designer should take into account to what external radiation the detector will be exposed and how important false alarm immunity is for the particular system. A detector that meets these criteria should be chosen or if necessary external radiation sources should be eliminated from the facility. Data on the detectors response to false stimuli can be found in the Phase I report.

C. FLOOR

Tests were conducted on the floor of the test facility to determine the effectiveness of the AFPDS from distances further away than tested in Phase I of this effort and to evaluate suppression of larger quantities of material. Pyrotechnic materials were tested in this configuration in quantities from ½ pound (227g) up to 2 pounds (908g).

The discharge sphere along with the high-speed detectors was located six-feet above the floor. In each evaluation the material tested was placed inside of an 18" square stainless steel pan with a one-inch lip. The material was ignited with an electric match, placed under the sample, and fired by a 6VDC firing box. Video was recorded with a VHS camera and a Kodak high-speed camera recording at 1000 frames per second. The following digital data was recorded at 1 kHz: match initiation time, individual detector reaction times, control panel alarm out, and follow-on water nozzle discharge times.

The system was modified for a few tests with six-foot high walls enclosing the pyrotechnic materials on three sides as seen in Figure 5. Each wall was four-feet wide. The walls were added to direct more water from the high-rate discharge sphere onto the pyrotechnic material.

Figure 5
Modified 6-Foot Test Setup

D. WORKSTATION

Tabletop tests were conducted to determine the effectiveness of the AFPDS against Phase II material fires in a workstation type setting. Such a setting in the plants and arsenals could involve inspection, cutting, extrusion, screening, pressing, de-milling operations, etc. Phase I and Phase II materials were also tested in this configuration to determine the suppressibility of up to two pounds (908g) of pyrotechnic material. This workstation consists of a 4' X 4' steel tabletop and a three-foot high lexan shield that surrounds the table on three sides. Figure 6 shows the test setup. The high-rate discharge sphere was positioned 35 inches above the workstation table along with the high-speed flame detectors at 33 inches.

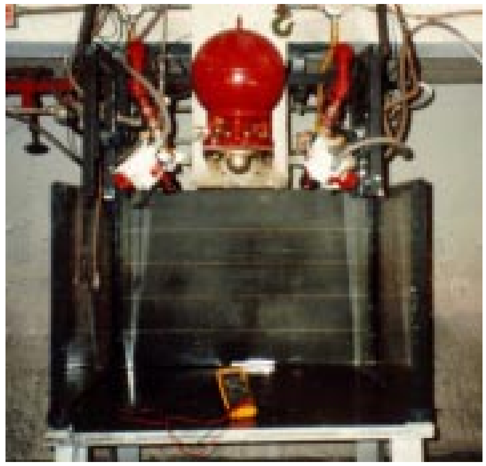


Figure 6
Workstation Test Setup

Up to two pounds (908g) of material was placed on the workstation table for each test. A heat flux sensor was placed 10-16 inches from the center of the material on the table. Pressure sensors to measure overpressure were mounted above the discharge sphere and eight feet above the table. The material was ignited with either an electric match fired by a 6-volt firing box or by an electric bridgewire, each placed under the sample. The bridgewire is nickel-chromium alloy (60/16), 10"long, coiled up to ¼" diameter. The bridgewire was heated, until glowing red hot, with a 30VAC power supply to a point that ignited the material. When the bridgewire configuration was used for ignition, the material to be tested was placed on a ceramic tile to prevent an electrical short from the bridgewire to the table. Trained and certified explosives ordinance technicians accomplished this part of the testing effort.

Video was recorded with one to three VHS cameras and a SVHS camera was used in a small number of tests. A Kodak tape system, a Kodak digital system and a Vision Research digital system were used during the course of testing to record high-speed images up to 1000 frames per second. The following digital data was recorded at up to 1 kHz: match or bridgewire initiation time, individual detector reaction times, control panel alarm out, and follow-on water nozzle discharge times. Analog data for heat flux and pressure measurements were measured at 2 KHz. A 486DX 33MHz computer and a 166MHz Pentium computer was used to record, save and analyze the analog data.

E. POWDER CHARGING MACHINE

The powder charging machine (PCM) is an apparatus used in an assembly line at Lake City AAP to automatically place the proper amount of pyrotechnic material into a casing. Two machines were shipped to Tyndall AFB for testing with the AFPDS. The machine was evaluated with the following three pyrotechnic materials, also from Lake City AAP: RS-40, RS-41 and R-440. Due to the design of this machine, some unique challenges were presented for applying the suppression agent to the proper location upon discharge.

Each test was conducted with ¼ to ¾ pounds (113 – 340 grams) of material located in the rubber storage bag at the base of the machine. Each test was ignited with one or two electric matches, manufactured by LunaTech, powered by a 6VDC firing system. In initial tests, a single match was used with gunpowder in the rubber bag for ignition purposes. Eventually, two matches were used for ignition with no gunpowder.

Initially, the high-rate discharge sphere and the high-speed detectors were installed above a metal shield that encases the PCM on the top and sides, shown in Figure 7. The top of the shield was constructed with perforations that were designed to allow air to flow in and out and to contain flames. The top of the shield was hinged in the middle with a funnel installed in the front half of the top. The funnel allows for pouring of the pyrotechnic material from above the shield into the rubber storage bag. After the first four tests, a plexiglass shield was installed in front of the machine to better simulate ammunition plant conditions and the follow-on water was not used.

Figure 7
Initial PCM Test Setup

Figure 8
¼" Steel Shield w/Sphere Above

After initial tests of the powder charging machine it was evident that RS-41 was the most hazardous material used in these machines. Future tests concentrated on RS-41. In the ammunition plant a "heavy-duty" shield is used for RS-41 operations, so a ¼" steel shield was constructed at Tyndall to better simulate actual plant conditions. All remaining tests were conducted with this new shield. The high-rate discharge sphere was installed in different configurations above, inside and on the side of the new shield.

For the side mount configuration, a "deluge valve" was constructed. The deluge valve was machined from a three-inch flange and designed to house the burst disk and explosive squib. The deluge valve was bolted to a 90-degree elbow, which was fastened to the bottom of the high-rate discharge sphere. The sphere and elbow were filled with water and charged to 500 psi. A 160° pattern nozzle was installed initially and then a 180° pattern nozzle. Eventually a 2 ½" cone-shaped nozzle was plumbed to the discharge of the deluge valve. In some tests this plumbing and cone was filled with water before the test. In these cases, paraffin wax was used to plug up the nozzle, acting as a blow-off cap.

Video was recorded with one to three VHS cameras and a SVHS camera was used in a small number of tests. A Kodak tape system, a Kodak digital system and a Vision Research digital system were used during the course of testing to record high-speed images up to 1000 frames per second. The following digital data was recorded at up to 1 kHz: match or bridgewire initiation time, individual detector reaction times, control panel alarm out, and follow-on water nozzle discharge times. Analog data for heat flux and pressure measurements were measured at 2 KHz. A 486DX 33MHz computer and a 166MHz Pentium computer was used to record, save and analyze the analog data.

F. HEAT FLUX

A high-speed heat flux sensor was installed for workstation, powder charging machine and for spectral analysis tests. Vatell's heat flux microsensor and AMP-6 amplifier was used to determine the heat flux that would be experienced by a worker under a fire scenario. This point source sensor was placed in a strategic position for each test and data was recorded at 2 KHz. The Vatell microsensor was chosen because of its reputation and speed, giving full scale response in 1ms with its protective face coating. The sensors fast response time is critical since the AFPDS system can suppress fires in as little as 28ms after ignition. The protective face coating, while slowing down sensor response time to 1ms, protected the sensor from the harsh environment of flame and fast moving water. The rest of the sensor was protected by a sealed metal enclosure approximately 4-inch by 2-inch by 4-inch.

Data from the sensor was recorded on a 486DX 33MHz computer and on a 166MHz Pentium computer. A 166MHz Pentium computer was used to analyze and chart the data.

G. SPECTRAL ANALYSIS

Spectral emissions from the pyrotechnic materials were measured in the AFPDS test facility. Material amounts ranging from 1/16 to ¼ pound (28 to 113g) were placed on the workstation table top and ignited with an electric bridgewire. Spectral emissions were measured with an Oriel Instaspec IV UV spectrometer and a Midac Fourier Transform Infrared (FTIR) Spectrometer, model # M2400-ZNSE. The Instaspec is a Czerny-Turner 1/4 meter spectrometer.

Video was recorded with one to three VHS cameras and a SVHS camera was used in a small number of tests. A Kodak tape system, a Kodak digital system and a Vision Research digital system were used during the course of testing to record high-speed images up to 1000 frames per second. The following digital data was recorded at up to 1 kHz: match or bridgewire initiation time, individual detector reaction times, control panel alarm out, and follow-on water nozzle discharge times. Analog data for heat flux and pressure measurements were measured at 2 KHz. A 486DX 33MHz computer and a 166MHz Pentium computer was used to record, save and analyze the analog data.

SECTION III

TEST METHODOLOGY AND RESULTS

High-speed deluge tests include several events where data collection is necessary for evaluation. Gagnon[3] listed 11 time segments that occur during a test and how they relate to NFPA 15[2] and system evaluations. Following is a list of the time segments during Phase II tests which were also listed in the Phase I report. These vary slightly from Gagnon:

1. <u>Event Initiation</u> - The button is pushed to ignite the electric match or to begin heating the bridgewire and start the test.
2. Deflagration begins.
3. <u>Detectable Event</u> - The first indication of a visible fire ball (deflagration), generated by the ignited material, as viewed on the high speed camera that should be "seen" by a detector. (Note: There were times during these Phase II tests that a detector detected the event before the detectable event (i.e. before the flame was visible). This is denoted as a negative (-) detection time in the following charts.)
4. The flame grows to a size where the radiation released is sufficient for detector reaction.
5. <u>Detector Alarm</u> - The fire detector sends a fire alarm signal to the control panel. The radiation required for detection varies with each detector's sensitivity and affects detection time.
6. <u>Controller Out</u> - The control panel, after receiving the signal from the flame detector, sends a signal to the water discharge devices.
7. The squib and solenoid valves receive the signal from the control panel and begin to react.
8. <u>Water Discharge</u> - Water exits the nozzle.
9. Water from the nozzle reaches the burning material.
10. <u>Fire Suppression (extinguishment)</u> - The first indication on the high speed camera of no fireball remaining.

A. FLOOR

Tests on the floor of the facility were conducted to determine the effectiveness of the AFPDS from distances further away than tested in Phase I of this effort and to evaluate suppression of larger quantities of material. Pyrotechnic materials were tested in this configuration in quantities from ½ pound (227g) up to 2 pounds (908g).

The discharge sphere along with the high-speed detectors was located 6 feet above the floor. An 160º hemispherical nozzle was mounted to the bottom of the sphere. In each test the material tested was placed inside of an 18-inch square stainless steel pan with a one-inch lip. The pan was placed on the floor of the facility in an open area.

In all tests, with the exception of one M206 test, the AFPDS contained the fire and easily suppressed it. The M206 test was not suppressed immediately because the suppression water did not reach the material in the quantities required for suppression. The reason for this was determined to be that the water spray pattern was not concentrated enough in the burning area. Walls were added to surround the burning material and to divert the 160º water spray, from six-feet above the material, to the fire source. After this the fire was suppressed. Figure 5 shows the test setup after the addition of the walls. Tables 1 shows detector response times for the listed materials placed six-feet away from the suppression system and high-speed detectors.

Table 1 Floor Tests: Average Detector Response Time(ms) Measured From the Detectable Event

	First Fire	Green Smoke	M125	M206	MK25	Red Lead	Yellow Smoke
Dual Spectrum	198	214	202	9	NA(1)	15	NA(1)
Fire Sentry	128	184	125	9	68	12	73
Spectrex	196	NA(3)	NA(1)	13	NA(1)	22(1)	NA(1)
Det Tronics	53	147	46	10	NA	17	61

* - Number of events missed are listed in parenthesis.

Events missed listed in parenthesis in Table 1 (and listed as DN in Appendix I) are not to be interpreted as a detector failing to alarm to a flame. A missed event was explained as follows in the Phase I report[1:] "All detectors responded to the size and duration flame that was expected in Phase I testing. During each test in Phase I all detector response times were measured for each test, however, the detector connected to the control panel that activated the suppression system was changed from test to test. In some tests, when a faster responding detector was connected to the control panel, the fire was extinguished before a slower responding detector had time to alarm, thus causing a missed event for the slower detector. If the fire had not been extinguished as expediently, the slower responding detector would have detected the event." <u>The missed event is entirely a test phenomenon and would not occur in a field application</u>.

Table 2 depicts the time from the event initiation, when the fire button was pushed to begin the event, until the detectable event. This is a measure of how long it takes a material to ignite upon the presentation of an energy source to it. In these floor tests the energy source was an electric match with a 6 VDC excitation voltage. Also, approximately 30g of gunpowder were placed over the electric match to aid in ignition. These times are not factored in when determining the response time of the system.

Complete test results of floor tests are listed in Table 1-3 in Appendix I. In each test the detectable event is time 0. The detectable event is defined as the first indication of a visible fireball generated by the ignited material, as viewed on the high-speed camera, that should be "seen" by a flame detector. Material suppression times are listed in the eighth column from the left. The suppression system was activated at the time shown in the *Controller Out* column. Individual detector response times are listed in the four columns on the right. The detector used to activate the system can be determined by finding the individual detector response time that equals the *Controller Out* time. The total time for suppression is usually measured from the time of flame detection and can be calculated by subtracting detection time from the time in the suppression column.

Table 2 Floor Tests: Average Interval from Event Initiation to Detectable Event

MATERIAL TESTED	TIME (MS)	MATERIAL TESTED	TIME (MS)
First Fire*	459	MK25	1032
Green Smoke	2966	Red Lead	22
M125	994	Yellow Smoke	688
M206	130		

* Note: The Ignition Device for the tests was an electric match.

B. WORKSTATION

A simulated typical workstation was set up for evaluating the AFPDS. This workstation is the test platform that was used exclusively for Phase I tests. It consists of a 4’ X 4’ steel tabletop and a three-foot high lexan shield that surrounds the table on three sides. The high-rate discharge sphere was positioned 35 inches above the tabletop along with the high-speed flame detectors at 33 inches. Figure 9 is a scene from a workstation test. The heat flux sensor can be seen to the left of the flame on the tabletop.

Figure 9
Workstation Test

Tables 3(a) and 3(b) show average response times for the flame detectors in all table top tests, measured in milliseconds with the detectable event as time zero. The quantity of material tested was not considered in these averages. Where a missed event occurs or when a detector was not evaluated for a test, the detector is assigned a detection time (for the purposes of calculating an average) based on its performance compared to the three detectors in all other tests with that particular material.

Table 3(a) Workstation Tests: Average Detector Response Time(ms) Measured From the Detectable Event

	RS-41	RS-40	Hy-Skor 700X	R-440	M14	JA-2	LKL
Dual Spectrum	40(1)	13(1)	21	90(1)	-67	224	276
Fire Sentry	24	7	32	70	35	162	365
Spectrex	28(1)	8(1)	36(3)	117(3)	45(2)	221(1)	408(3)
Det Tronics	NA	11	39(1)	54	35	-209	-22

* - Number of events missed are listed in parenthesis.

Table 3(b) Workstation Tests: Average Detector Response Time(ms) Measured From the Detectable Event

	LX-17	PBX-9501	PBX-9502	Red Lead	Green Smoke	M206	First Fire
Dual Spectrum	16(2)	55	30	7	-514	3	NA(2)
Fire Sentry	14(2)	49	19	7	476	4	221
Spectrex	NA(5)	NA(6)	NA(3)	5	NA(3)	1	NA(2)
Det Tronics	-139	-11**	-448	11	NA(3)	NA	148

* - Number of events missed are listed in parenthesis.
** - One detection at –5481 not factored in.

Table 4 depicts the time from the event initiation, when the fire button was pushed to begin the event, until the detectable event. This is a measure of how long it takes a material to ignite upon the presentation of an energy source to it. In these table top tests the energy source was a bridgewire with a 30 VAC excitation voltage. These times are not factored in when determining the response time of the system.

Table 4: Average Interval from Event Initiation to Detectable Event

MATERIAL TESTED	TIME (MS)	MATERIAL TESTED	TIME (MS)
RS-40*	2645	PBX-9501 (Match)	1042
RS-41	6644	PBX-9502 (Match)	705
R-440	2195	Red Lead	584
Hy-Skor 700X	501	Yellow Smoke	5770
M14	2160	Green Smoke	6053
JA-2	2299	M206	812
LKL	1377	First Fire	844
LX-17 (Match)	2097		

* Note: The Ignition Device for the tests was an electric bridgewire unless otherwise indicated as a match.

All of the Phase II materials were tested in the workstation setup. All of these materials were successfully extinguished. In addition, the following Phase II materials were tested in quantities up to two pounds, also with successful extinguishment: RS-40, R-440, and propellants Hy-Skor 700X, M14, JA-2, and LKL.

Five Phase I material results are included in the above charts and were tested in quantities up to two pounds (908g) with no follow-on water. All of these materials were successfully extinguished with the following exception: in two of the three M206 tests conducted with two pounds of material, the water from the sphere was insufficient to completely suppress the material, although there was a significant amount of unburned material after the test. In this case, the follow-on water would have aided in achieving suppression. Although the solenoid activated follow-on water was not needed in all but two of our tests, it is recommended that this system (solenoid activated follow-on water) be installed for most applications to provide for a longer discharge of water which will also meet NFPA 15[2] requirements. For example, an in-place heat activated device (HAD) could be modified with solenoid nozzles to backup the AFPDS.

Complete test results of workstation tests are listed in Tables 1-1 and 1-2 in Appendix I. Also, see heat flux results later in this section. In each test the detectable event is time 0. The detectable event is defined as the first indication of a visible fireball generated by the ignited material, as viewed on the high-speed camera, that should be "seen" by a flame detector. Material suppression times are listed in the eighth column from the left. The suppression system was activated at the time shown in the *Controller Out* column. Individual detector response times are listed in the four columns on the right. The detector used to activate the system can be determined by finding the individual detector response time that equals the *Controller Out* time. The total time for suppression is usually measured from the time of flame detection and can be calculated by subtracting detection time from the time in the suppression column.

C. POWDER CHARGING MACHINE

The powder charging machine is an apparatus used in an assembly line at Lake City AAP to automatically place the proper amount of pyrotechnic material into a casing. Two machines were shipped to Tyndall AFB for testing with the AFPDS. The machine was evaluated with the following three pyrotechnic materials, also from Lake City AAP: RS-40, RS-41 and R-440. Due to the design of this machine, some unique challenges were presented for applying the suppression agent to the proper location upon discharge.

The powder charging was initially tested in the AFPDS test facility with ¼ pound (113g) of RS-40, RS-41 and R-440. The high-rate discharge sphere and the high-speed detectors were installed above the metal shield shipped with the machine that encases the machine on the top and on three sides. The test was designed to determine if enough water could get through the perforations in the top of the machine and through the funnel, located on the top of the machine, into the storage bag to achieve suppression without major modifications to the machine or the suppression system. Representatives from the Army witnessed a portion of these tests. Each test was conducted with ¼ to ¾ pounds (113 – 340g) of material located in the rubber storage bag at the base of the machine.

Suppression times, measured from time of detection, during these tests varied from 20 to 90ms for RS-40 and R-440 and from 17 to 229ms for RS-41. It was clear that

RS-41 was the material that propagated the fastest and was the most challenging of the three materials to suppress. A modification was made to this test setup by opening the top of the powder charging machine shield, which is perforated to allow air flow in and out but contain flames, and by adding a large funnel (approximately three-feet square) to the top of the shield. The reasoning was to allow water from the sphere to reach the material faster and in greater quantities. However, this did not make a significant difference in test results.

For subsequent tests, a ¼-inch steel shield similar to the one used at Lake City AAP for RS-41 operations was constructed and tested with the powder charging machine. All remaining powder charging machine tests were conducted with ¾ pounds of RS-41. This shield encased the powder charging machine on all sides except the top. Openings were placed on the sides for a conveyer belt, and the front was constructed of lexan with a steel frame.

Two tests were conducted without the sphere discharging to determine the impact when the AFPDS was not used. The first test was conducted with no suppression and the second with currently installed follow-on water activated by the Detector Electronics UV detector. The original shield and ¾ pounds of RS-41 was used in each test. A dummy was placed outside the shield as shown in Figures 10-15 for each test. In the unsuppressed test, Figures 10-11, the dummy's hair melted 2-3 inches, the lexan shield between the machine and the dummy was severely damaged, and the dummy's rubber gloves showed signs of melting. In the test with only follow-on suppression, Figures 12-13, again the dummy's hair melted 2-3 inches, there was damage to the workers gloves and the fire was suppressed in 299ms. A previous test with the dummy, the AFPDS and the ¼" steel shield, as seen in Figures 14 and 15, showed no damage to the dummy (the dummy was wet after the test) and slight damage to the lexan shield. Suppression time was 89ms.

Figure 10
No Suppression – Before

Figure 11
No Suppression – After

Figure 12
Follow-On Suppression – Before

Figure 13
Follow-On Suppression – After

Figure 14
Sphere Suppression – Before

Figure 15
Sphere Suppression – After

In the next test configuration, the sphere was placed on the side of the powder charging machine shield to match a potential configuration in the Lake City AAP plant. This is the configuration shown in Figure 14. A deluge valve was constructed for this test. The burst disk and explosive squib was mounted in the deluge valve. The deluge valve was bolted to a 90° elbow that was fastened to the bottom of the high-rate discharge sphere. The sphere and elbow were filled with water and charged to 500 psi. The burst disk in the deluge valve was located 16 inches away from the storage bag for these tests. A 160° pattern nozzle was installed in the first test and a 180° pattern nozzle in the second. The friction in the pipe slowed down the discharge of the water and suppression times were 88 and 185ms respectively. Another test was conducted with the sphere burst disk located 22 inches away with a 2 ½" cone-shaped nozzle (Figure 17) and a suppression time of 105ms.

The high-rate discharge sphere and high-speed detectors were then mounted over the top of the machine, 29 inches above the storage bag. In two tests, the suppression times, measured from time of detection, were 127 and 112ms respectively. A funnel was installed in the machine like the one used at Lake City AAP and the sphere was moved up to also protect the top of the funnel. Suppression times ranged from 93 to 216ms with the sphere at this location, 42 inches away from the storage bag. The nozzle on the high-rate discharge sphere was changed from a 160-degree nozzle to a 90-degree nozzle for a single test. The fire was contained in 216ms and suppressed in 424ms.

Three tests were conducted with two spheres discharged at the same time, one located above and one on the side of the powder charging machine shield. The three-inch pipe attached to the deluge valve on the side-mounted sphere was filled with water for these tests and paraffin wax, acting as a blow-off cap, placed in the 2 ½" cone-shaped nozzle. The top mounted sphere was placed to protect the funnel and the powder charging machine. The 160° nozzle was used on the top mounted sphere. Suppression times for these tests, measured from time of detection, were 54, 141 and 117ms.

Figure 16
PCM Top and Side Mount

Figure 17
2 ½" Cone-Shaped Nozzle

The sphere was then mounted inside the powder charging machine shield, 11 inches above the rubber bag. A faster detector for the application (AFRL/MLQC prototype) was used in these tests to activate the system. Suppression times ranged from 59 to 91ms.

One test was conducted with the new shield and with no suppression. The fire burned for 1.4 seconds and caused 100% scorching of the lexan shield located on the front of the powder charging machine.

Suppression times varied but were generally the same for each of the above tests conducted with the ¼-inch steel shield encasing the machine. However, with the sphere mounted inside the shield, 11-inches from the material, suppression times were significantly reduced and the system lessened the potential for damage to personnel and property.

A new ultra high-speed detector developed by AFRL/MLQC was tested in some of the latter powder charging machine tests. In each case, the detector saw the flame and alarmed before it could be seen on the high-speed video at 1000 frames per second (fps) or at 500 fps. The use of this detector reduces system response time by two or more milliseconds as compared to the other detectors tested. This is important when dealing with materials that propagate as fast as the RS-41 pyrotechnic evaluated in these tests.

The development of this detector will continue at the conclusion of Phase II, and it will be used to trigger the AFPDS to control mixing bowl fires up to 25 pounds.

Significant overpressures were noticed in several tests. The ¼-inch steel shield surrounding this operation is necessary to contain these overpressures.

D. HEAT FLUX

A high-speed Vatell heat flux microsensor was installed for workstation, powder charging machine and for spectral analysis tests to determine the heat flux that would be experienced by a worker under a fire scenario. This point source sensor was placed in a strategic position for each test based on the expected test results.

Appendix II shows the heat flux data in graphical form from unsuppressed spectral analysis tests and from suppressed workstation tests. During the spectral analysis tests the heat flux sensor was set-up 24-inches from the burning material for most tests. This distance was chosen to replicate the average distance that a person would be working. The amount of material burned in most of these tests was 1/8 pound (57g) or 1/16 pound (28g). For workstation tests, material weight varied from ¼ pound (114g) to 2 pounds (908g). The sensor distance varied from 10 to 16 inches for each test, measured from the center of the burning material.

The charts in Appendix II show the heat flux data, two heat flux curve standards and when suppressed, a vertical line indication of the initiation of the suppression system. All charts in Appendix II include the MIL-STD 398 curve. This curve represents the military standard for suppressive shielding as defined in MIL-STD 398[4]. Anything above that line is unacceptable at that distance. Some of the charts also include another reference curve extrapolated from data taken from Stoll and Chianta[5]. Anything above this line would cause a second-degree burn to human skin at the distance measured.

Some of the materials evaluated in the spectral analysis open burns exceeded the limits of MIL-STD 398 with 1/16 pound (28g) of material burning 24-inches away from the sensor. Other materials were safe with this amount at that distance. As the material weight was increased and the sensor was moved closer to the burning material during suppression tests, the results of using the AFPDS are clearly seen.

RS-41 at 1/16 pound (28g) clearly exceeded MIL-STD 398 in open burns from 24-inches (Graphs II-3 & II-4 in Appendix II), however the material was safe from 16-inches with the suppression system activating on four times as much material (¼ pound (114g)) shown in Graph II-25. 1/16 pound (28g) of Red Lead was marginally safe at 24-inches in an open burn. However with 32 times as much material, two pounds (908g), and the sensor only 10-inches away from the material, Red Lead was still marginally safe at 10-inches in the first test. In a second two-pound test however, it exceeded the MIL-STD 398 limits for approximately 40-50 ms. Graphs II-15, II-16, and II-31-II-33 show the Red Lead test results. M206, tested in two open burns at 1/16 pound (28g) and measured at a distance of 24-inches, clearly exceeded the limits of MIL- STD 398. In a suppressed ¼ pound (114g) test, however, the heat flux generated minimally exceeded the MIL-STD limits, even at a distance of 10-inches from the flame. M206 test results are shown in Graphs II-19, II-20, and II-35. These results show that workers can be protected.

E. SPECTRAL ANALYSIS

The high-speed flame detectors evaluated in the Phase I and Phase II AFPDS project can respond to deflagrations in 2-10 milliseconds. They do this by sensing radiation from flames in the ultraviolet (UV) and infrared (IR) regions of the light spectrum. Although the detectors have responded to the materials evaluated in this project, it is known that optimization of the detectors is possible. Therefore spectral data was measured in this Phase II project from the pyrotechnic and propellant burns. A total of 23 materials were tested to record spectral emissions data.

Infrared data was measured in the 2-20µm region of the electromagnetic spectrum with a Midac Fourier Transform Infrared (FTIR) Spectrometer, model # M2400-ZNSE. UV data was measured with a Oriel Instaspec IV UV spectrometer in the 180-260nm region. Appendix III displays selected charts of IR emissions of the pyrotechnic materials tested during spectral analysis evaluations. Selected UV data charts are included in Appendix IV.

Each material evaluated has unique spectral regions and intensities where radiation is emitted during combustion. By tuning a detector to respond to these emissions, detector response can be optimized for each material. The spectral features of the additional pyrotechnic materials (found in Appendix III pages 88-96) displayed interactions within the mid IR range of 4.3-12.6 µm (2300 cm^{-1} – 790 cm^{-1}). These features were caused by the carbon dioxide and water produced from the reactions. Peaks from the fragments of the system were expected to contribute to the spectral information. However, there were no other spectral features pertaining to the chemical composition of these pyrotechnic materials.

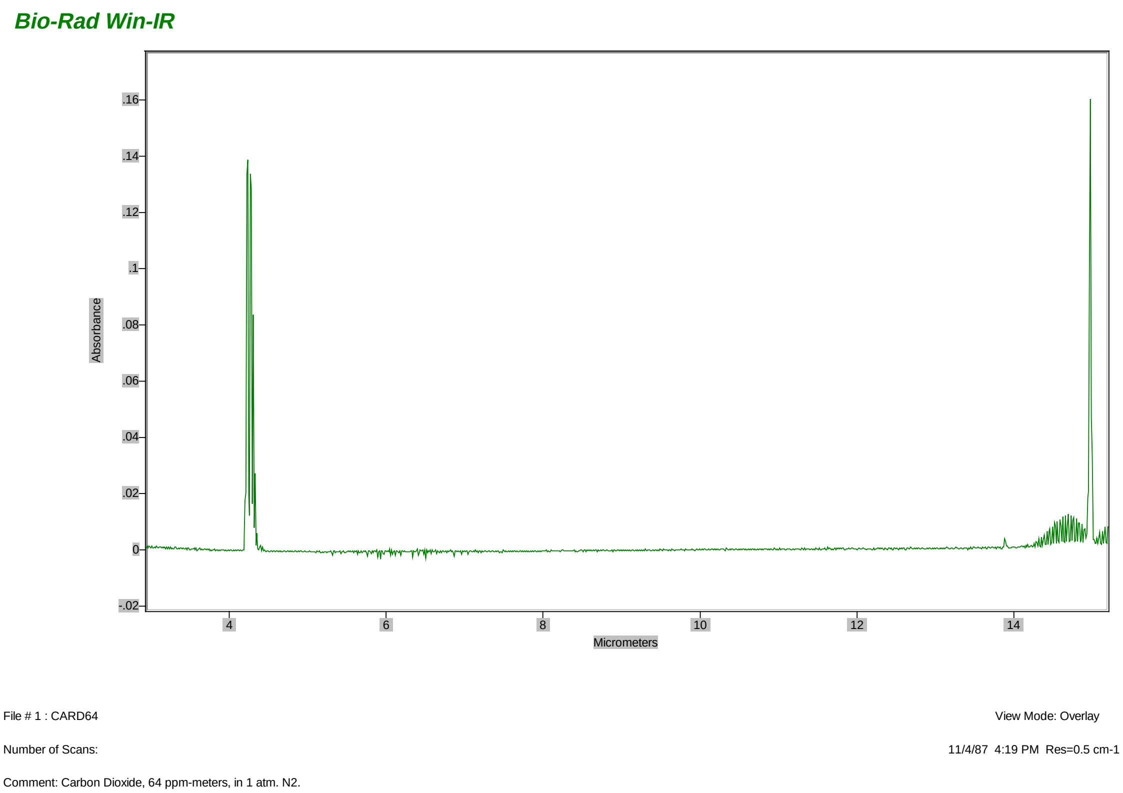
This data is to be used by detector manufacturers to adjust the measurement parameters of their detectors to achieve optimal performance for each material, or by contract officers to specify detection parameters, specific to the materials involved, for a suppression system installation. Complete spectral data is available in the CD-ROM version of this report. Infrared data is presented in a .spc format and can be viewed with such programs as Lab Calc or Grams. This data includes a multifile containing 200 spectra for each test, on average four tests per material. These 200 data points were taken over a 10-12 second period beginning at the initiation of each test. Ultraviolet data is presented in a ASCII format on the CD-ROM. There are 100 spectra of UV data per test. Copies can be requested by contacting Mr. Robert Loyd at the U.S. Army Industrial Operations Command Safety Office at Rock Island Arsenal, IL.

Spectra was collected from exposures of the different pyrotechnic materials in the UV to Mid UV area (180 - 350 nm). Although air cuts off absorption at 200 nm, a very intense signature was observed at the 180- 190 nm area. The shapes are well defined bands indicating molecular emission with perhaps identified line emissions immersed in the spectrum. Other significant peaks were located in the 300-310 nm area. These signatures were clearly defined and would suggest that enhancing detector sensitivity in those areas would significantly enhance detection probability.

The IR spectra were carefully analyzed by comparing the data emission spectra to standard IR absorption spectra for CO_2 and water. These two standard spectra explain essentially all of the features observed in the data. Additional standard gas spectra would have been compared if other gas absorption/emission bands were indicated.

The standard CO_2 absorption spectrum, shown in Graph 1, is characterized by a two hump fine structure between 4.2 and 4.3 microns with a central valley at 4.25 microns. In the test data, neither these two humps nor the fine structure of a typical gas molecule are resolved. Only a very strong emission band at about 4.25 is seen in the data. CO_2 also has a two hump fine structure pattern from 14.4 to 15.6 with a center peak at 15.0, but this feature was barely visible in only a few of the data spectra.

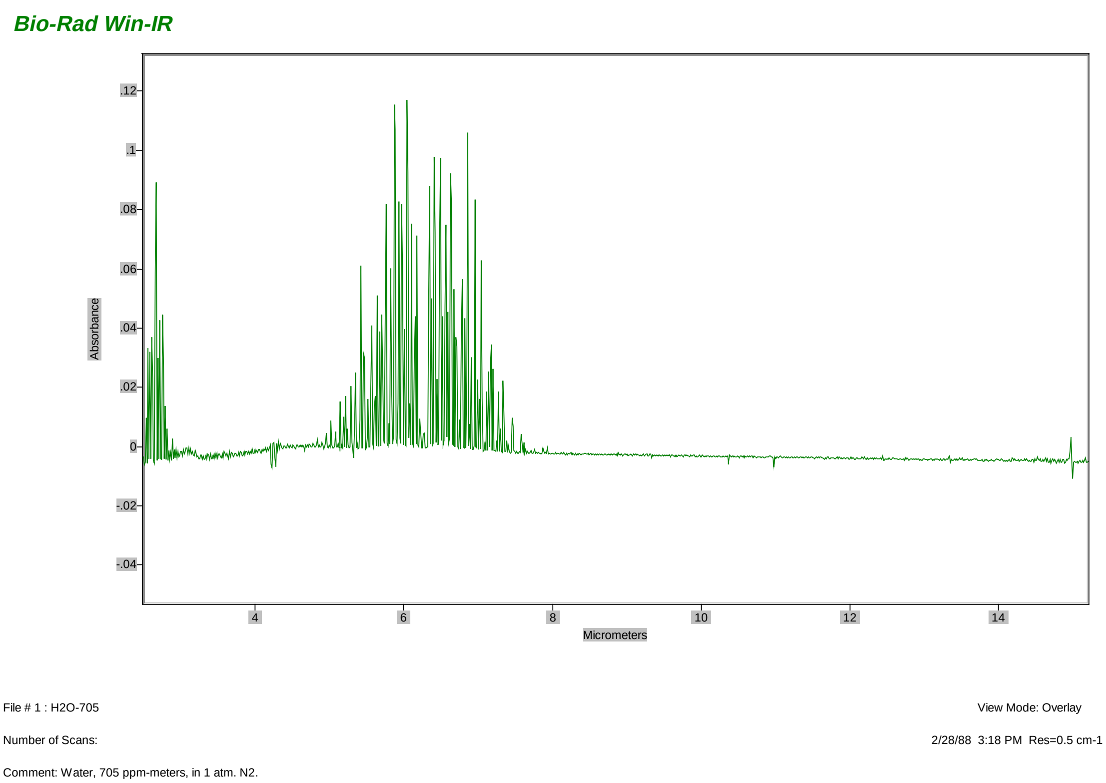
Graph 1: CO_2 Absorption Spectrum



The standard water absorption spectrum contains two strong and wide fine structure patterns. Graph 2 shows the strongest absorption structure is a two-hump pattern from 5 to 7.5 microns with a valley at 6.3. This characteristic water structure can be seen in almost all of the test data. The fine structure in each hump looks like noise ridding on top of the background level. The presence of water emission can be confirmed in the test data by looking for the second water structure between 2.5 and 2.8. In the test data, the fine structure is not resolved and appears as one fairly strong peak right on the left edge of the spectral windows.

All of the test spectra have a broad and strong peak between 10 and 13 microns. This peak is in all of the background spectra as well. It is probably the natural black body curve radiating from the scene and the internal optics of the instruments at ambient temperature. In a few test spectra fairly well defined peaks appear between 2 and 10 microns, not identifiable as CO_2 or water emission. In most cases these peaks match up exactly with bumps in the background spectra, so they are probably just the amplified background spectra caused by the increased temperature of the scene during the fire.

Graph 2: H_2O Absorption Spectrum



The spectra indicate that a dual detection approach (UV- IR) would probably enhance detection and reduce the rate of false alarms significantly.

SECTION IV

CONCLUSIONS AND RECOMENDATIONS

The concept of protecting personnel working in these hazardous areas is two-fold: first, put water on the burning material as soon as possible, second put water on personnel as soon as possible to protect their skin from burning.

CONCLUSIONS

1. The AFPDS can be easily installed to protect people and equipment in real life working situations as found at ammunition plants and arsenals. This was demonstrated by installing the system in a powder charging machine as used at the Lake City AAP. The installation of the AFPDS, when completed, will provide substantial improvements over that protection now provided by current suppression systems at Lake City AAP.

2. The AFPDS can be modified to improve the performance of most of the currently installed high-speed suppression systems installed in munitions plants. For example, an in-place heat activated device (HAD) could be modified with solenoid nozzles to backup the AFPDS.

3. Materials, such as RS-41, whose burn rates can vary dramatically, should be protected with two or more separate detectors, one that protects for the case of slow flame propagation and one that protects for fast flame propagation. Currently, in many installations, two identical detectors are used to monitor the same area for redundancy. This unique idea is to provide two separate detectors to improve system performance and to also assure redundancy.

RS-41, when burned in the powder charging machine, would propagate in one of two ways: 1) very fast or, 2) slow at first, then very fast. In the first case, one would want the fastest detector available to activate the deluge system. The second case is more complicated. Test results show that the fastest detectors for fast propagating events can be the slowest detectors for slow propagating events. This phenomenon is due to the detector design and logic. In the case of a slow growing fire, the objective is to extinguish the flame before the propagation rate significantly increases. The detector of choice here is the one that detects the slow growing fires the fastest. A combination of the fastest detector for fast growing events and the fastest detector for slow growing events should be used to activate the suppression system in areas where materials like these are used. This report and the Phase I report have detection times for each material tested and for each detector.

For RS-41 a good detector combination to provide protection would be the Spectrex detector and the Fire Sentry detector evaluated in this test series. RS-41 data is shown in Appendix I (consider controller out <20ms as fast growing and controller out>20ms as slow growing). Spectrex detects the fast growing events the fastest and Fire Sentry detects the slowest growing events the fastest. (Note: Testing proved that for redundancy, the Fire Sentry will detect a fast growing event as a backup to the Spectrex, and the Spectrex will detect a slow growing event as a backup to the Fire Sentry.)

4. All of the Phase II materials were successfully detected and extinguished in the workstation test. Six of these materials were tested in two pounds (908g) quantities. Most of these tests were conducted with only the AFPDS sphere extinguisher and no follow-on water.

5. Five Phase I materials were also tested with two pounds (908g) of material and the AFPDS with no follow-on water. All of these materials were successfully extinguished, however in two of the three M206 tests conducted with two pounds of material, the water from the sphere was insufficient to completely suppress the material, although there was a significant amount of unburned material after the test. In this case the follow-on water would have aided in achieving suppression. Although the solenoid activated follow-on water was not needed in all but two of our tests, it is recommended that this system (solenoid activated follow-on water) be installed for most applications to provide for a longer discharge of water which will also meet NFPA 15[2] requirements. For example, an in-place heat activated device (HAD) could be modified with solenoid nozzles to backup the AFPDS.

RECOMMENDATIONS

Follow on work beyond the Phase II effort would build upon the knowledge gained in previous work to improve the AFPDS to assure detection and suppression of larger fires, such as mixing bowls, before an explosion can occur. These events can involve up to twenty pounds of material and are, from our experience, virtually impossible to suppress or extinguish as a general rule with current systems. Material burns of propellant were conducted with amounts as large as 25 pounds. However, this material was relatively slow burning as compared to such mixtures as RS-41 and M206. During testing in Phase II a much faster acting detector than the four commercial models tested was demonstrated and cut overall system speed from 6-9 ms to 3-6 ms. With more refinement of the AFRL developed detector, it is believed that an AFPDS can be built to successfully extinguish larger amounts of material including the fast burning magnesium based mixtures.

It has been demonstrated both in the Phase I and the Phase II programs that the highly energetic materials such as M206 and RS-41 are devastating to people and facilities unless suppression is provided in the incipient stages of a fire. Currently, the AFPDS, is 90% faster than the NFPA standard of 100 milliseconds for water at the nozzle. Consistently, response time has been in the range of 6–12 ms depending upon the detector used. It is believed, however, that even these speeds can be increased. In some cases, this could be the difference between saving life or preventing major damage to a facility.

Early testing of a new detector using transistor technology shows outstanding potential of achieving even faster response times for the large fires previously mentioned.

It is believed that an improvement of up to 75% could be achieved by this detector. This equates to a response time to the highly energetic materials in as little as two milliseconds, which is phenomenal when compared to the current standard of 100 ms. Since the effort under Phase I and Phase II started, the Army continues to lose people and facilities because currently installed systems are unable to suppress propagation. Any follow on effort should also involve the strongest effort possible to finalize and develop the AFPDS and initiate POM action to program for the installation of these systems at plants and arsenals. Members of the commercial sector including detector manufacturers, suppression system companies and organizations engaged in installation, maintenance and operation of munitions manufacturing processes should be encouraged to participate.

SECTION V

REFERENCES AND BIBLIOGRAPHY

REFERENCES

1. Carr, V., Cozart, K.S., Wells, S.P. Advanced Fire Protection Deluge System Phase I Report. Air Force Research Laboratory, Fire Protection Group, Tyndall Air Force Base, FL 32403, July 1998

2. NFPA 15. Water Spray Fixed Systems for Fire Protection. National Fire Codes. National Fire Protection Association, Inc. Quincy, MA. 1996.

3. Gagnon, Robert N. Ultra High Speed Suppression Systems for Explosive Hazards. Fire Protection Handbook, Eighteenth Edition, National Fire Protection Association, 1997.

4. MIL-STD-398

5. Stoll, Chianta. *Aerospace Medicine, Vol 40*, 1968.

BIBLIOGRAPHY

1. DOD Ammunition and Explosives Safety Standards, DOD 6055.9-STD, July 1999.

2. Loyd, Robert A., Wells, Steven P., Advanced Fire Protection Deluge System, Minutes of the 28th Explosives Safety Seminar, Department of Defense Explosives Safety Seminar, 19 August 1998.

3. AMC Safety Manual, AMCR 385-100, 26 Sep 1995.

4. Loyd, Robert A., Evaluation of Ultra-High-Speed Fire Protection Systems Presently in Service at Army Ammunition Plants, U.S. Army Armament, Munitions and Chemical Command Safety Office, Department of Defense Explosives Safety Seminar, August 1994.

5. Military Handbook – Fire Protection for Facilities Engineering, Design, and Construction, MIL-HDBK-1008C, 15 January 1994.

6. Goedeke, A.D., Fadorsen, G.A. Evaluation of State-of-the-Art High Speed Deluge Systems Presently in Service at Various U.S. Army Ammunition Plants. WL-TR-93-3510. September 1993.

7. Knape, R., Accident Summary for the MJU-8 Flare Mix Fire at Longhorn AAP, 28 September 1992, 18 August 1992, Minutes of the 25th Explosives Safety Seminar, Department of Defense Explosives Safety Seminar.

8. Loyd, Robert A., Investigation of Igniter Composition Fire, Bay 9, Building G-11, Lonestar Army Ammunition Plant, 18 August 1992 Minutes of the 25th Explosives Safety Seminar, Department of Defense Explosives Safety Seminar.

9. Loyd, Robert A., Design and Installation of Ultra-High-Speed Deluge Systems, Minutes of the 24th Explosives Safety Seminar, Department of Defense Explosives Safety Seminar, 27 August 1990.

10. Kennedy, P.E., O'Brian, G.P., Patel, S.H. Study to Investigate Portable Ultra High Speed Deluge Systems, U.S. Army Production Base Modernization Activity, Contract # DAAA21-86-D-0033, August 1988.

11. Loyd, Robert A., Ultra-High-Speed Deluge Systems for Advanced Operations, Minutes of the 23rd Explosives Safety Seminar, Department of Defense Explosives Safety Seminar, 9 August 1988.

12. Evaluation of Pyrotechnic Fire Suppression System for Six Pyrotechnic Compositions, TR No. AD-E401 306, March 1985, APR.

13. Minutes of the Rapid Action Fire Protection System Seminar, U.S. Army Armament, Munitions and Chemical Command, 23-24 October 1984.

14. Engineering Guide for Fire Protection and Detection Systems at Army Ammunition Plants, Vol II (Testing & Inspection), TR No. AD-E400 874, December 1982, Distribution limited to U.S. Government Agencies only – contains proprietary information.

15. Engineering Guide for Fire Protection and Detection Systems at Army Ammunition Plants, Vol I (Selection and design), TR No. AD-E400 531, December 1980, APR.

16. McIntyre, F.L., Rindner, R.M., A Compilation of Hazard Test Data for Pyrotechnic Compositions, Report # ARLCD-CR-80047, ARRADCOM, TSD. March 1979.

17. Vargas, Luis M., Garza, Luis R., Caltagirone, Joseph P., Pyrotechnic Fire Suppression System Evaluation, U.S. Army Armament Research, Development and Engineering Center.

18. DA PAM 385-64, Ammunition and Explosives Safety Standards, 28 Nov 1997.

APPENDIX I

WORKSTATION TEST DATA

Table I-1 Table Top Test Results of Phase II Materials (time in ms)

MaterialName	Test #	Material Weight (g)	Ignition Device	Event Initiation	Controller Out	Containment	Suppression	Dettronics	Dual Spectrum	Spectrex	Fire Sentry
RS-40	53	114	Bridgewire	-3323	4	32	46	10	10	4	4
RS-40	54	114	Bridgewire	-3394	8	35	43	11	8	4	5
RS-40	55	114	Bridgewire	-2565	8	31	37	10	DN	10	8
RS-40	121	509	Bridgewire	-2508	9	63	72	13	14	12	9
RS-40	153	577	Bridgewire	-1866	9	30	37	12	18	10	10
RS-40	122	992	Bridgewire	-2216	10	255	359	11	13	9	10
RS-41	56	114	Bridgewire	-1953	66	86	91	FA	DN	DN	66
RS-41	57	114	Bridgewire	-10109	4	29	35	FA	10	4	5
RS-41	58	114	Bridgewire	-12958	11	46	53	FA	11	5	5
RS-41	75	114	Bridgewire	-1555	24	276	298	10	41	24	18
R-440	59	114	Bridgewire	-2096	57	78	83	26	57	DN	31
R-440	60	114	Bridgewire	-2496	78	98	105	21	55	78	34
R-440	61	114	Bridgewire	-1865	181	172	204	148	187	DN	181
R-440	156	939	Bridgewire	-1505		41	44				
R-440	62	96	Bridgewire	-3113	22	41	43	22	DN	DN	34
R-440	157	963	Bridgewire	-2097		80	84				
Hy-Skor 700X	51	114	Bridgewire	-705	0	25	30	DN	0	DN	35
Hy-Skor 700X	52	114	Bridgewire	-696	2	37	44	14	-6	12	7
Hy-Skor 700X	123	447	Bridgewire	-416	40	58	72	NT	31	DN	40
Hy-Skor 700X	131	454	Bridgewire	-472	37	68	84	49	35	DN	38
Hy-Skor 700X	154	893	Bridgewire	-356	35	52	61	49	33	42	36
Hy-Skor 700X	155	899	Bridgewire	-360	32	49	58	44	33	40	36
M14	64	114	Bridgewire	-2351	41	58	66	21	-178	41	17
M14	65	114	Bridgewire	-2790	12	30	33	21	-166	15	12
M14	66	114	Bridgewire	-2343	11	26	28	11	-91	12	12
M14	164	907	Bridgewire	-1714	4	24	32	NT	4	DN	16
M14	165	908	Bridgewire	-1600	94	112	134	NT	94	DN	120
JA-2	67	114	Bridgewire	-1984	377	395	398	-1078	384	377	33
JA-2	68	114	Bridgewire	-2813	14	31	35	11	14	21	12
JA-2	69	114	Bridgewire	-1187	898	917	920	-196	905	DN	898
JA-2	70	114	Bridgewire	-2594	11	28	33	11	11	15	10
JA-2	166	906	Bridgewire	-2592	10	24	30	NT	16	10	10
JA-2	167	906	Bridgewire	-2624	14	22	28	NT	14	0	8
LKL	71	114	Bridgewire	-749	660	678	683	-81	660	DN	673
LKL	72	114	Bridgewire	-806	842	860	865	-89	721	DN	842
LKL	73	114	Bridgewire	-904	787	805	811	8	586	787	610
LKL	74	114	Bridgewire	-2419	12	21	24	12	-346	DN	18
LKL	163	907	Bridgewire	-1594	16	34	50	NT	16	22	26
LKL	162	908	Bridgewire	-1788	16	34	40	NT	16	18	18
LX-17	36	114	match	-672	17	35	37	-15	16	DN	17
LX-17	37	114	match	-643	37	56	59	11	12	37	10
LX-17	38	114	match	-1135	34	55	57	-4	34	DN	15
LX-17	39	114	match	-775	3	21	22	3	DN	DN	DN
LX-17	47	114	match	-370	15	188	213	-313	0	32	-4
LX-17	48	114	match	-2475	18	37	44	-13	25	DN	18
LX-17	49	114	match	-9996	453	473	478	-679	6	453	28
LX-17	50	114	match	-711	0	18	20	0	DN	DN	DN
PBX 9501	27	114	match	-120	15	30	38	6	17	21	15
PBX 9501	30	114	match	-560	3	23	26	3	11	DN	12
PBX 9501	31	114	match	-6345	20	35	41	-5481	26	DN	20
PBX 9501	32	114	match	-125	52	70	73	-52	52	DN	35
PBX 9501	40	114	match	-410	6	27	29	6	11	DN	17
PBX 9501	41	114	match	-195	116	138	140	1	97	116	67
PBX 9501	42	114	match	-172	211	231	233	-52	218	DN	211
PBX 9501	43	114	match	-408	10	33	35	8	10	DN	14
PBX 9502	28	114	match	-94	21	41	45	N/A	12	21	15
PBX 9502	33	114	match	-1145	18	37	42	-468	18	DN	16
PBX 9502	34	114	match	-236	105	125	128	-155	72	105	27
PBX 9502	35	114	match	-1277	24	43	44	-1184	33	DN	24
PBX 9502	46	114	match	-773	15	36	38	14	15	DN	14

Table I-2 Table Top Test Results of Phase I Materials and Additional Materials (time in ms)

MaterialName	Test #	Material Weight (g)	Ignition Device	Event Initiation	Controller Out	Containment	Suppression	Dettronics	Dual Spectrum	Spectrex	Fire Sentry
Red Lead	116	455	Bridgewire	-539	6	23	36	11	7	5	6
Red Lead	120	902	Bridgewire	-748	7	25	123	11	7	6	7
Red Lead	119	911	Bridgewire	-466	8	27	137	11	7	4	8
Yellow Smoke	114	454	Bridgewire					DN	0	DN	DN
Yellow Smoke	115	922	Bridgewire	-5770	31	48	50	-809	31	DN	-709
Green Smoke	111	227	Bridgewire	-4842	164	182	186	DN	-190	DN	164
Green Smoke	112	454	Bridgewire	-5869	244	259	263	DN	-673	DN	244
Green Smoke	113	908	Bridgewire	-7449	1019	1035	1038	DN	-678	DN	1019
M206	161	807	Bridgewire	-848	2		2200	NT	2	0	2
M206	160	946	Bridgewire	-776	2		176	NT	4	2	6
First Fire	158	934	Bridgewire	-772	400	418	426	262	DN	DN	400
First Fire	159	934	Bridgewire	-916	42	62	68	34	DN	DN	42
Acetone	91		match	0	0	0	0	15	29	DN	13
Acetone	92		match	-9	0	0	0	38	118	140	56
Acetone/M206	106	195	Match	-787	26	44	48	31	8	DN	26
Acetone/M206	107	197	Match	-26							
Acetone/M206	105	208	Match	-6	16	37	44	21	21	DN	16
Acetone/M206	93	226	Match	-750	21	38	42	-3	17	21	13
Black Mag.	134	454	Match	-16	8	27	35	NT	8	DN	11

FA – False Alarm
NT – Not Tested
DN – Did Not Alarm

Table I-3 Floor Test Results of Phase I Materials (time in ms)

Material Name	Test ID	Material Weight	Ignition Device	Event Initiation	Controller Out	Containment	Suppression	Dettronics	Dual Spectrum	Spectrex	Fire Sentry
First Fire	11	454	match	-568	256	321	347	49	193	256	100
First Fire	12	908	match	-350	202	266	283	57	202	135	155
Green Smoke	2	681	match	-511	191	247	261	47	191	DN	100
Green Smoke	6	454	match	-4326	259	317	442	259	166	DN	240
Green Smoke	7	908	match	-4060	284	334	358	134	284	DN	211
Gun Powder	10	10	match	-1	0	0	46	25	DN	DN	DN
M125	13	454	match	-1023	389	439	520	19	327	389	176
M125	14	908	match	-965	74	130	142	72	77	DN	74
M206	18	454	match	-17	5	86	234	9	5	3	5
M206	20	454	match	-23	4	142	184	9	6	4	7
M206	21	908	match	-451	39	374	567	11	19	39	16
MK25	4	454	match	-921	46	89	104	off	DN	DN	46
MK25	5	908	match	-1142	206	259	275	93	80	206	89
Red Lead	3	454	match	-65	59	118	927	39	40	59	29
Red Lead	15	454	match	0	15	208	550	8	8	15	7
Red Lead	16	908	match	-13	6	131	191	15	8	6	6
Red Lead	17	454	match	-23	10	78	199	11	11	DN	10
Yellow Smoke	8	454	match	-440	70	130	144	62	69	70	56
Yellow Smoke	9	908	match	-935	89	154	162	60	DN	DN	89
M206*	23	454	match	-27	4	71	102	9	6	4	6
Red Lead*	22	454	match	-11	7	44	214	13	9	9	7

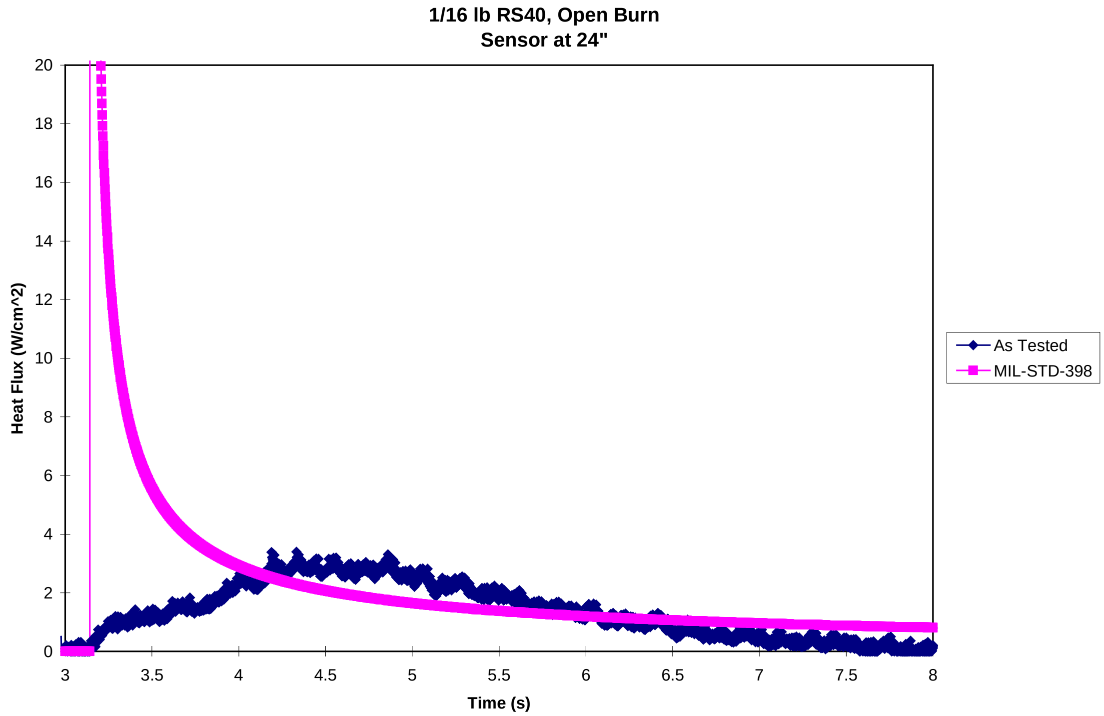
* - Tested with three walls around material
DN – Did Not Alarm

Table I-4 Powder Charging Machine Test Results of RS-41 (time in ms)

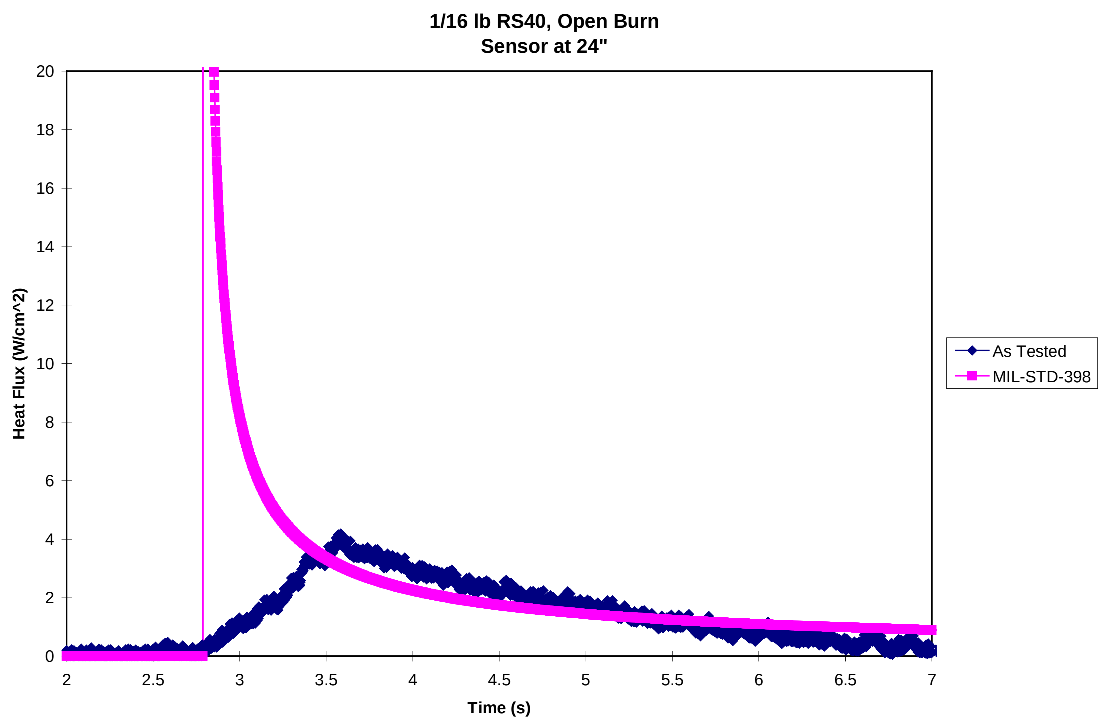
Test ID	Material Weight (g)	Test Apparatrus	Detector Distance	Sphere Distance	Sphere Size	Follow-on Water	Event Initiation	Controller Out	Containment	Suppression	Dettronics	Dual Spectrum	Spectrex	Fire Sentry
76	104	PCM-Orig	36	36	10	YES	-53	3	82	137	9	7	3	7
79	102	PCM-Orig	24	26	10	YES	-101	4	76	113	8	9	4	6
80	114	PCM-Orig	24	26	10	NO	-28	3	170	232	10	7	3	4
81	105	PCM-Orig	24	26	10	NO	-268	1	22	48	6	DN	1	8
82	137	PCM-Orig	24	26	10	NO	-327	4	118	147	10	9	4	7
83	137	PCM-Orig	24	26	10	NO	-54	4	129	177	10	10	4	5
87	222	PCM-Orig	24	26	10	NO	-31	2	88	172	8	6	2	6
88	366	PCM-Orig	24	26	10	NO	-41	3	121	196	9	7	3	7
90	352	PCM-Orig	24	26	10	NO	-431	84	96	101	-29	17	84	-6
94	359	PCM-Orig	24	26	10	NO	-751	15	116	156	15	13	15	17
97	366	PCM-Orig	24	26	10	NO	-539	39	52	58	-32	11	39	-2
98	366	PCM-Orig	24	26	10	NO	-643	53	124	194	-15	23	53	11
99	363	PCM-Orig	24	26	10	NO	-839	0	172	224	-456	-130	0	-11
104	343	PCM-Orig	24	26	30	NO	-42	2	172	226	9	6	2	3
102	353	PCM-Orig*	24	26	30	NO	-436	189	200	266	-99	28	189	3
103	353	PCM-Orig*	24	26	30	NO	-530	197	209	577	5	30	197	22
109	344	PCM-Orig*	24	26	30	NO	-76	3	94	231	9	6	3	7
126	440	PCM-side	24	16	30	NO	-25	3	95	188	9	5	3	7
148	334	PCM-side	24	22	10	NO	-25	2	96	108	8	4	3	6
130	345	PCM-side	24	16	30	NO	-25	3	76	91	8	6	3	4
132	344	PCM-Orig	24	NA	NA	NO		NA	NA	NA	NA	NA	NA	NA
133	349	PCM-Orig	24	NA	NA	YES	-42	5		299	5	NT	NT	NT
117	340	PCM-New	27	29	30	NO	-82	9	116	136	9	16	9	6
118	345	PCM-New	27	29	30	NO	-52	2	103	114	8	5	2	2
135	346	PCM-funl	45	42	10	NO	-62	4	137	191	10	7	4	5
136	330	PCM-funl	45	42	10	NO	-52	1	53	94	9	5	2	6
137	334	PCM-funl	45	42	10	NO	-24	2	70	132	9	5	3	4
138	334	PCM-funl	45	42	10	NO	-12	5	194	221	8	12	5	6
139	333	PCM-funl	45	42	10	NO	-38	1	86	105	7	6	2	4
141	345	PCM-funl	NA	NA	NA	NO	-60	NA	NA	1400	NA	NA	NA	NA
142	335	PCM-funl	45	42	10	NO	-40	1	217	425	6	7	2	2
146	325	PCM-top&sd	NA	NA	10	NO	-51	2	45	56	10	6	3	5
149	346	PCM-top&sd	NA	NA	10	NO	-30	-2	116	139	9	68	5	9
150	337	PCM-top&sd	NA	NA	10	NO	-53	-2	85	115	7	10	3	6
151	328	PCM-inside	24	11	10	NO	-32	-2	64	89	8	6	2	5
152	329	PCM-inside	24	11	10	NO	-43	-1	48	58	8	6	3	5

APPENDIX II

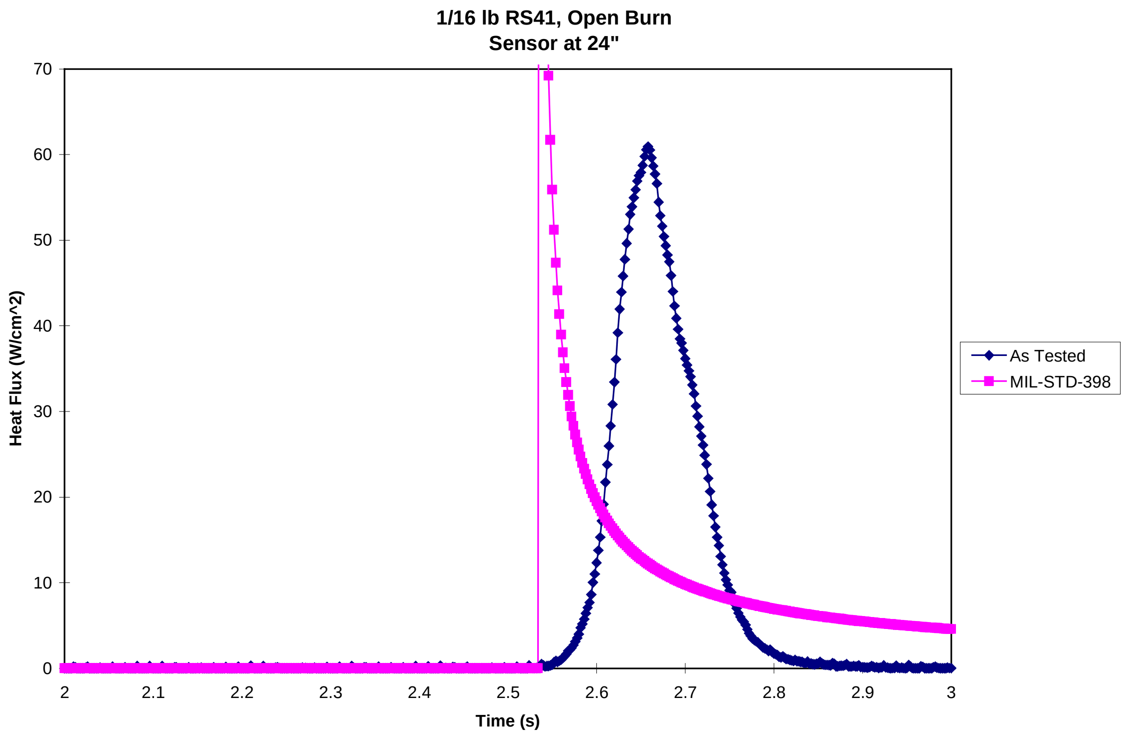
HEAT FLUX CHARTS



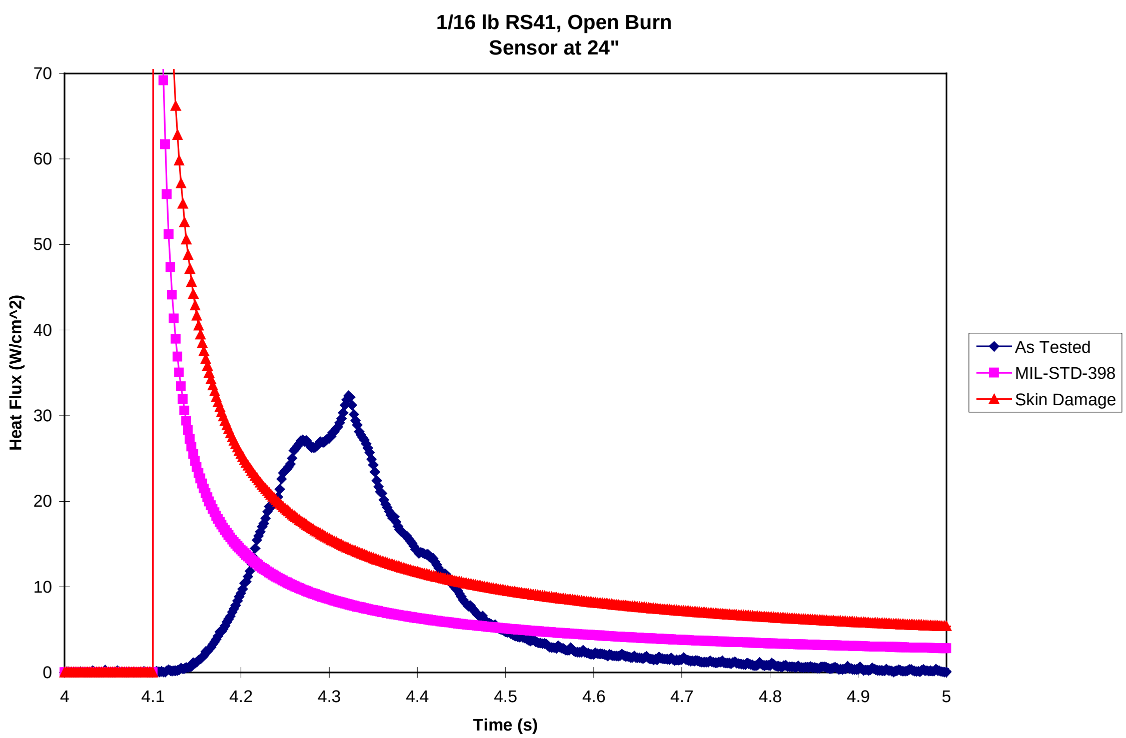
Graph II-1: 1/16# RS-40 Open Burn



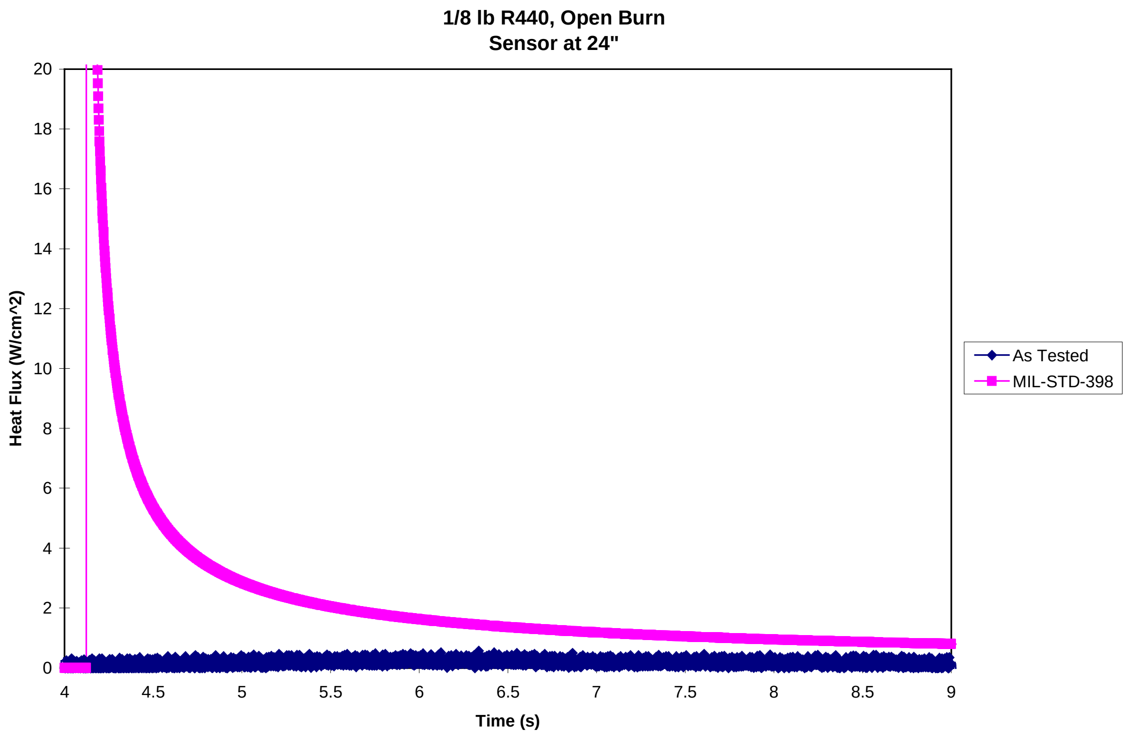
Graph II-2: 1/16# RS-40 Open Burn



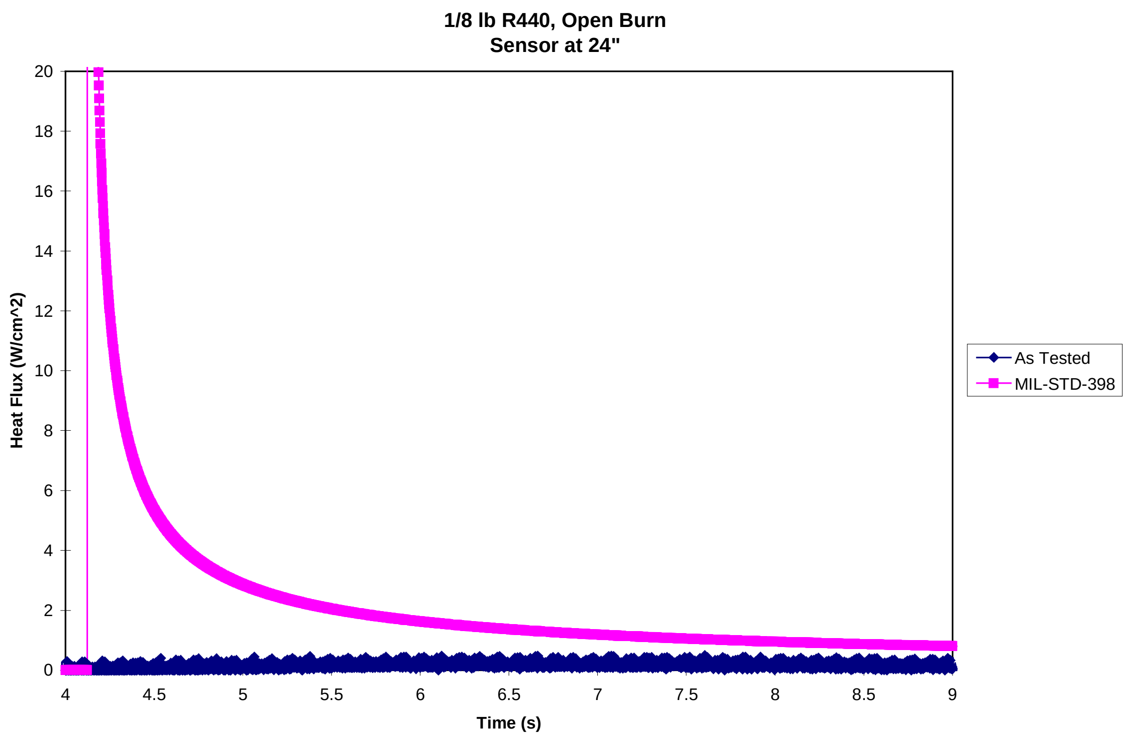
Graph II-3: 1/16# RS-41 Open Burn



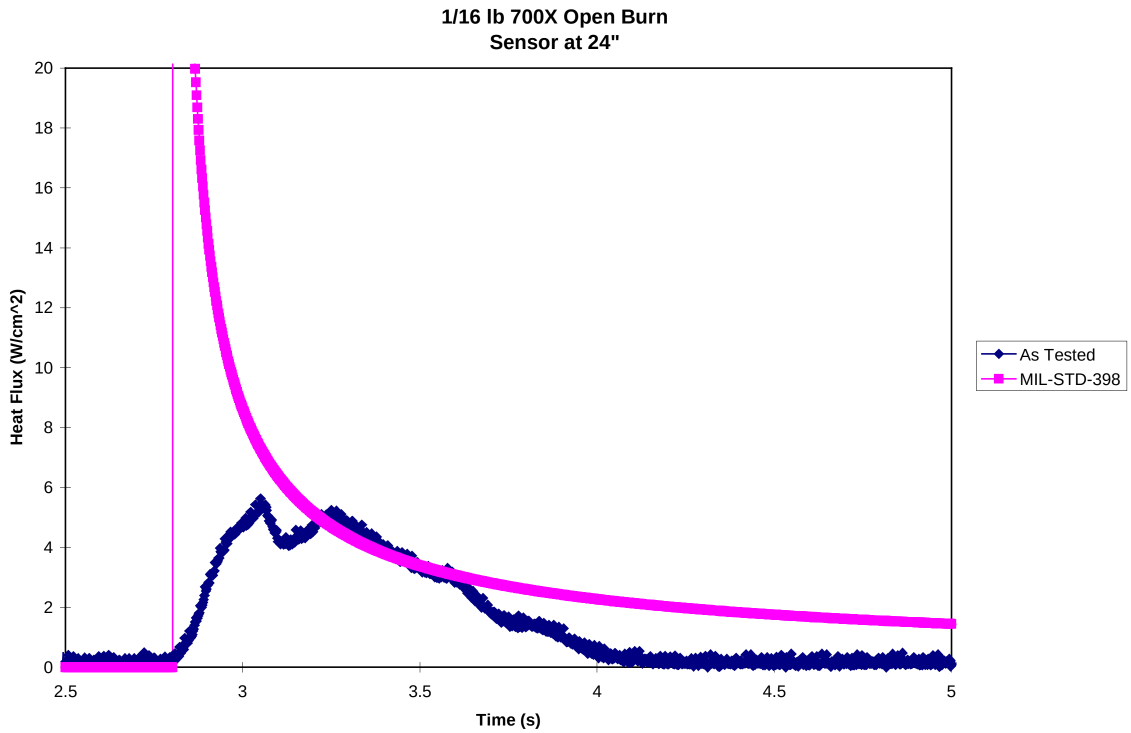
Graph II-4: 1/16# RS-41 Open Burn



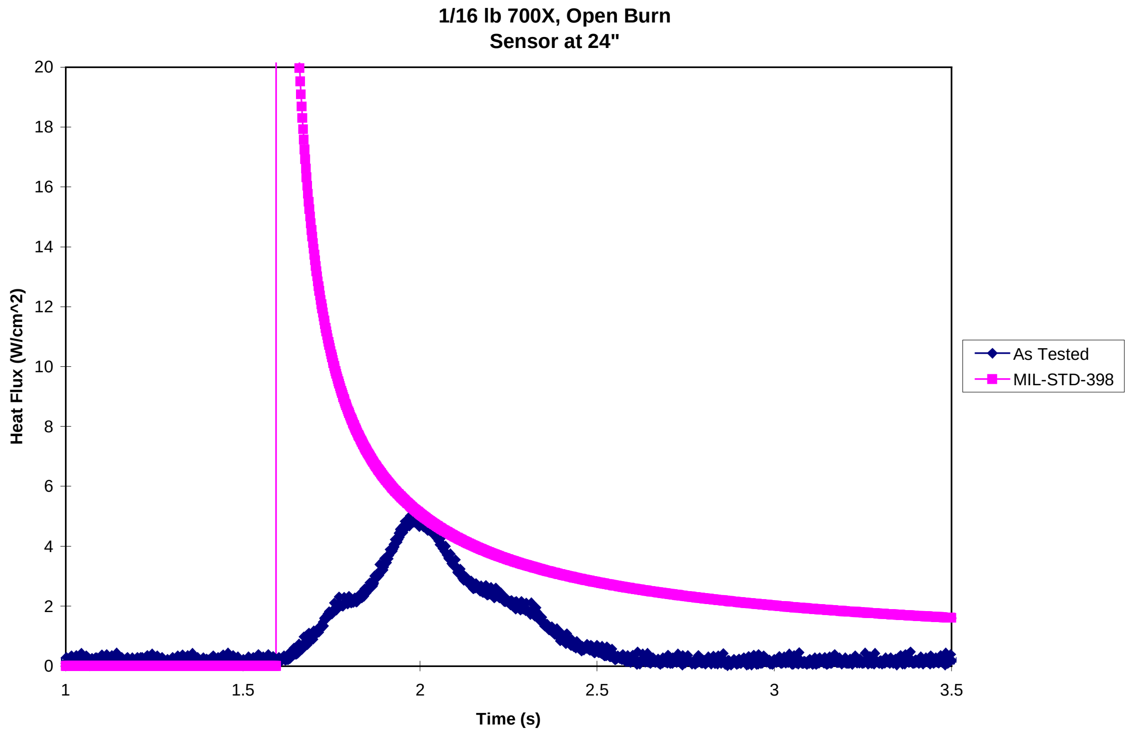
Graph II-5: 1/8# R440 Open Burn



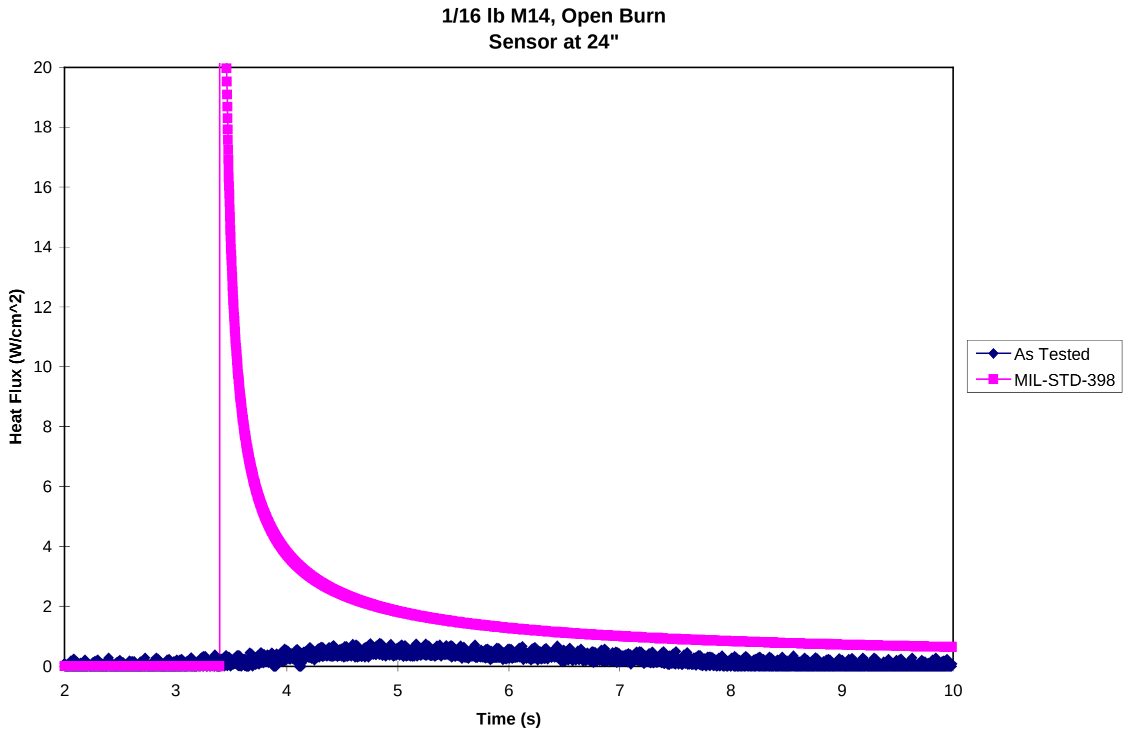
Graph II-6: 1/8# R440 Open Burn



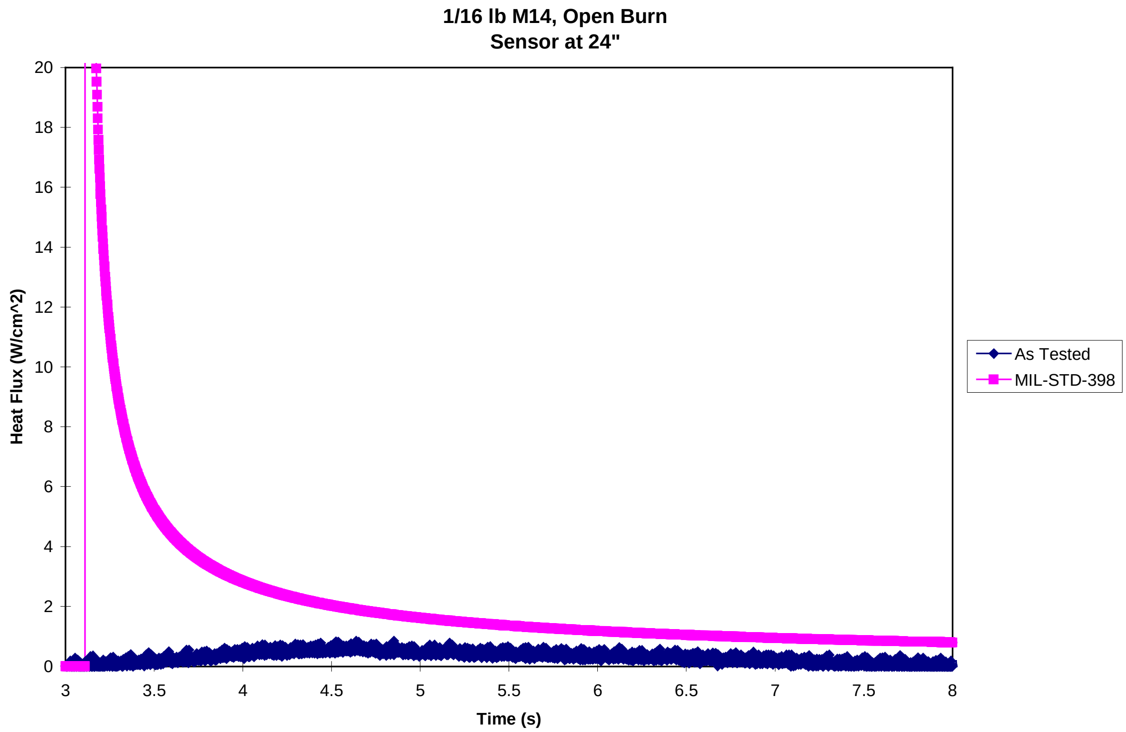
Graph II-7: 1/16# Hy-Skor 700X Open Burn



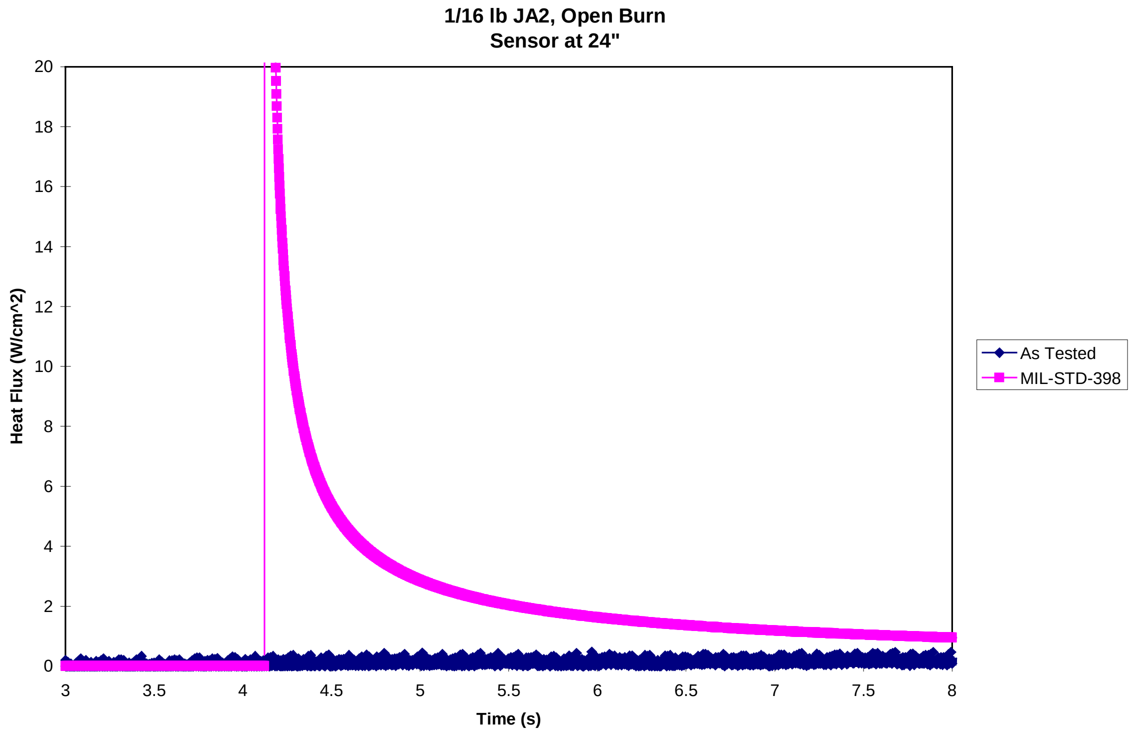
Graph II-8: 1/16# Hy-Skor 700X Open Burn



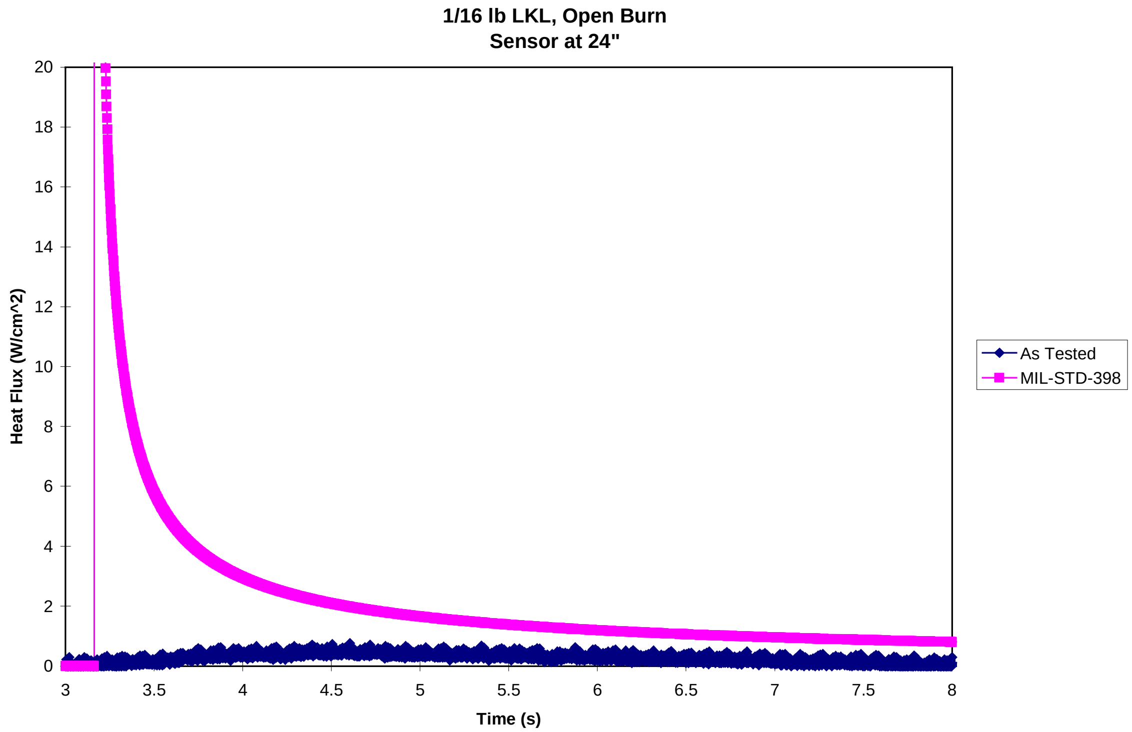
Graph II-9: 1/16# M14 Open Burn



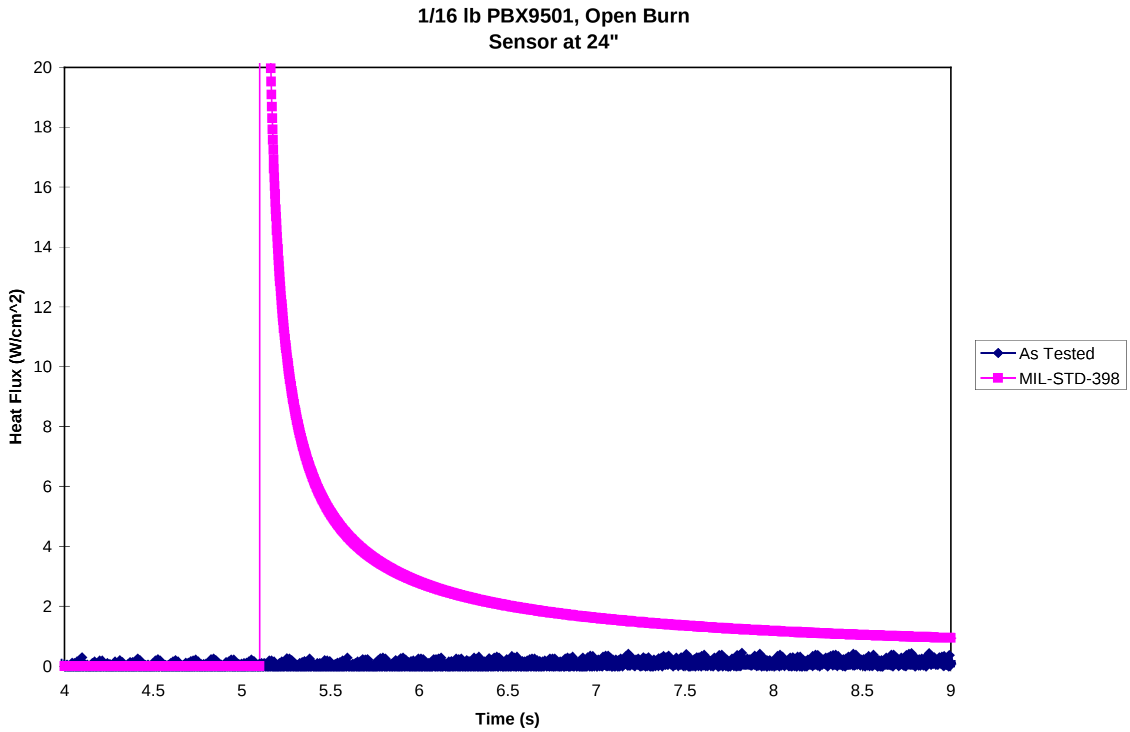
Graph II-10: 1/16# M14 Open Burn



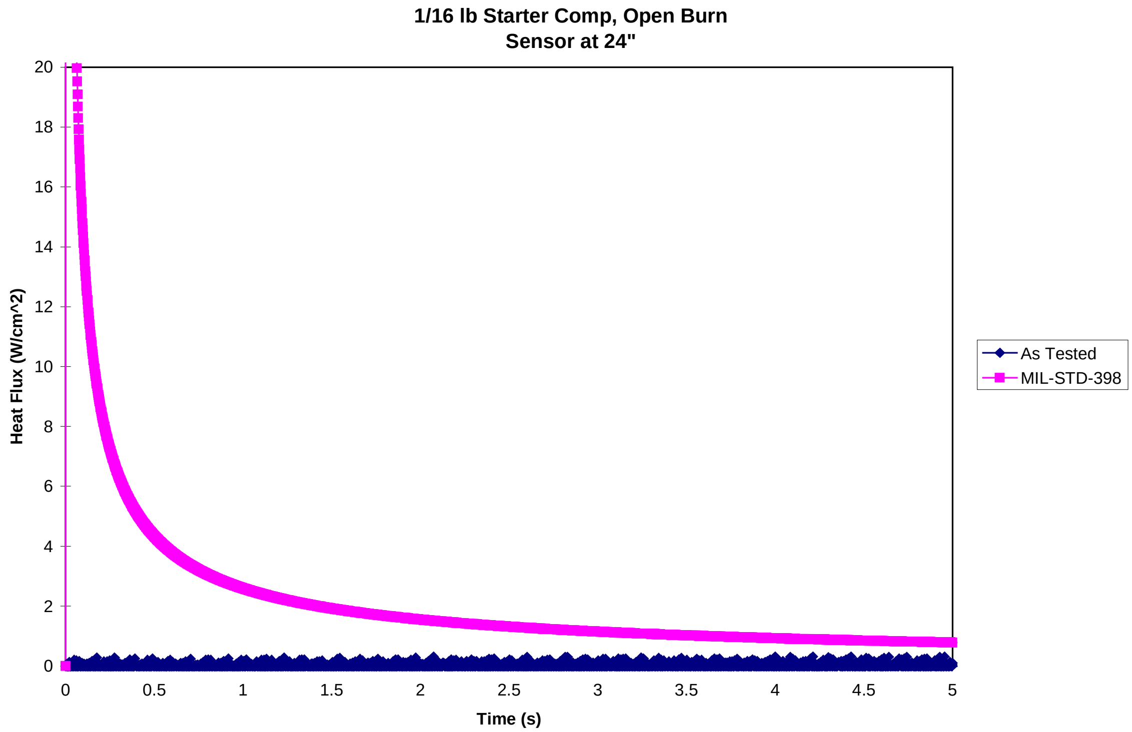
Graph II-11: 1/16# JA-2 Open Burn



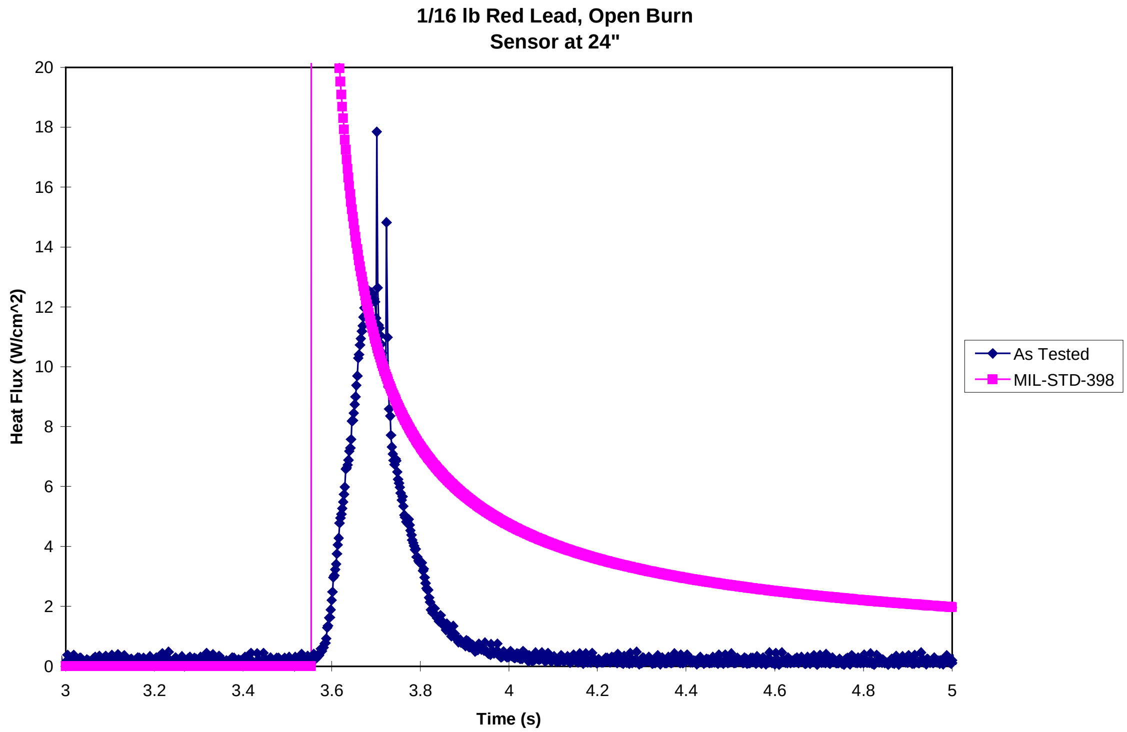
Graph II-12: 1/16# LKL Open Burn



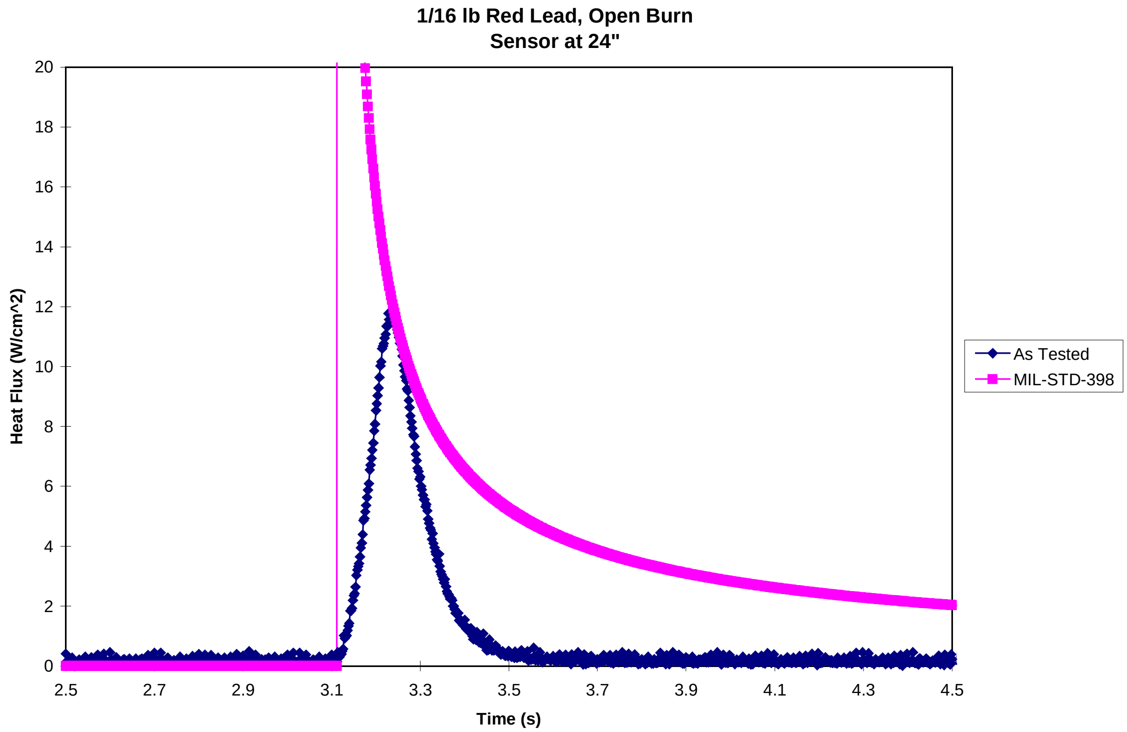
Graph II-13: 1/16# PBX9501 Open Burn



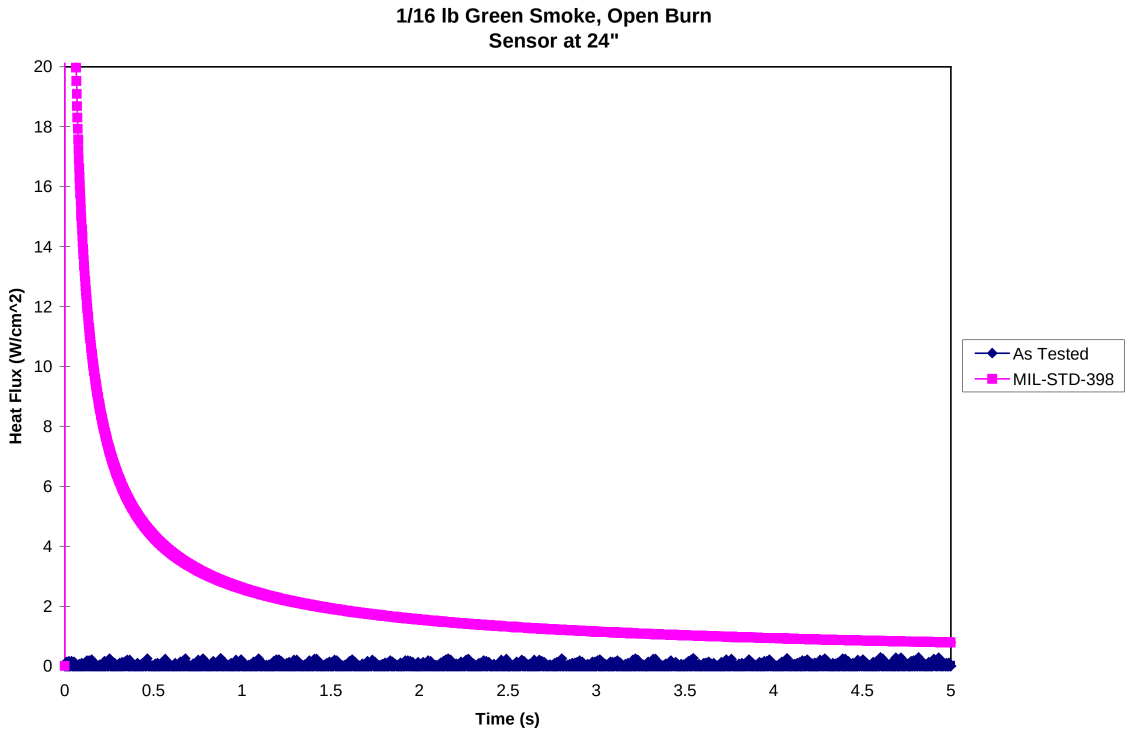
Graph II-14: 1/16# Starter Comp Open Burn



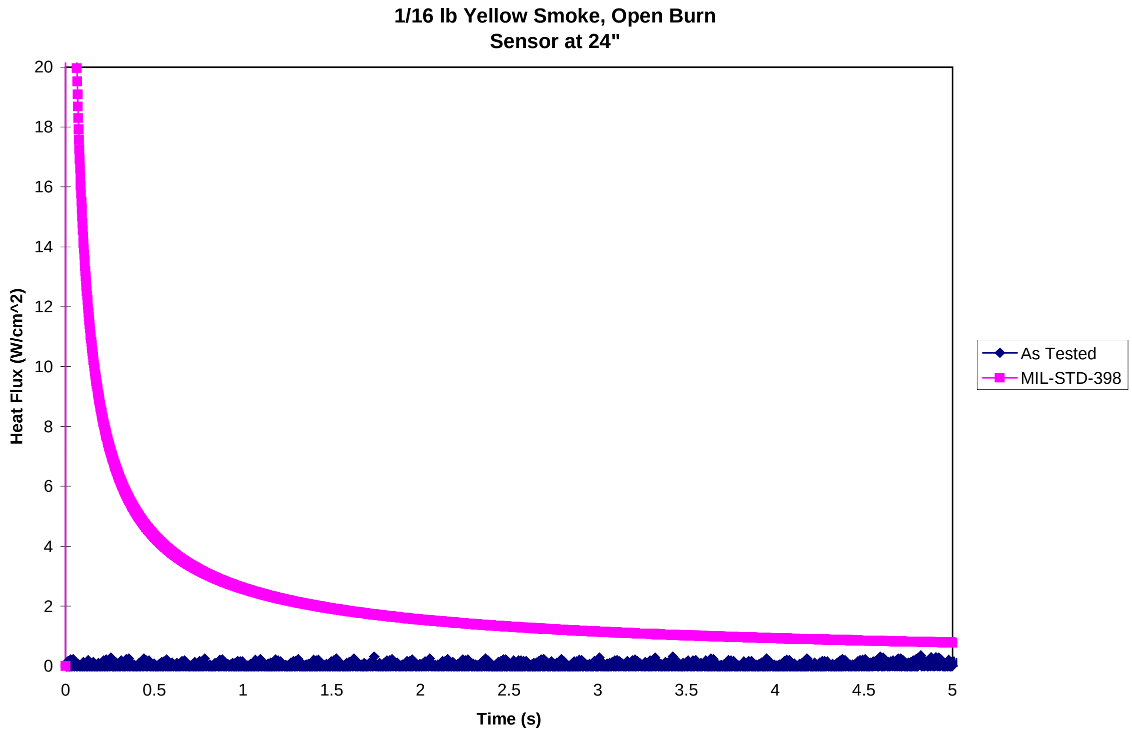
Graph II-15: 1/16# Red Lead Open Burn



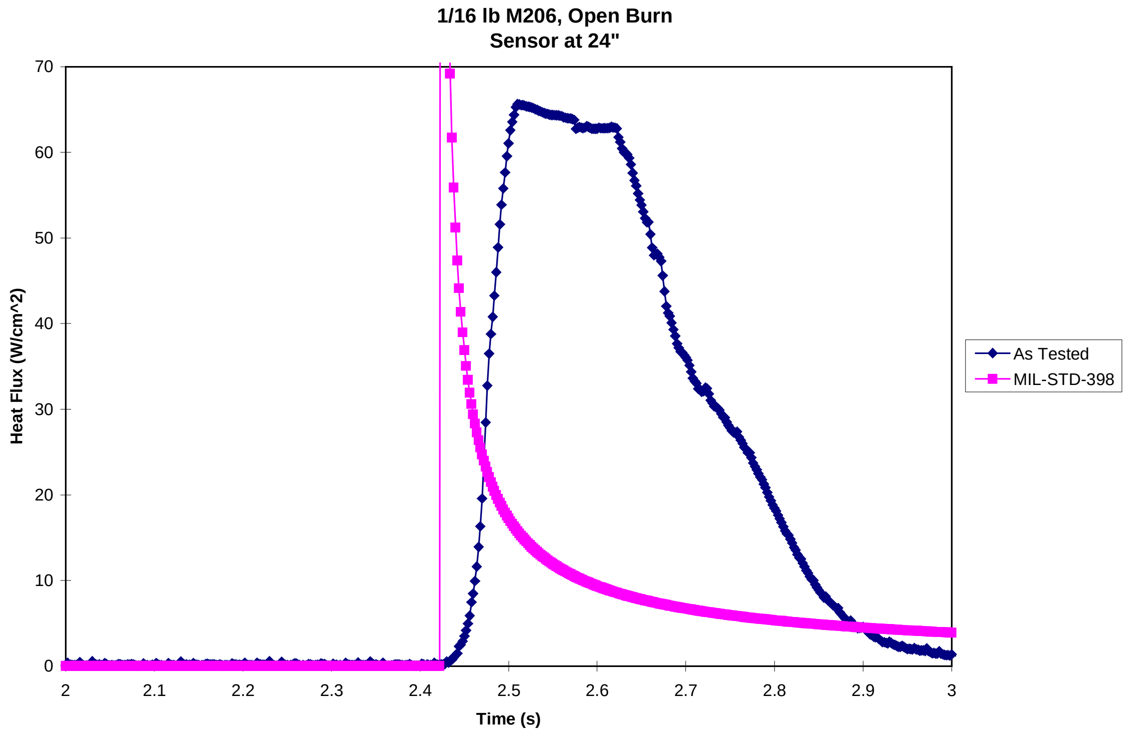
Graph II-16: 1/16# Red Lead Open Burn



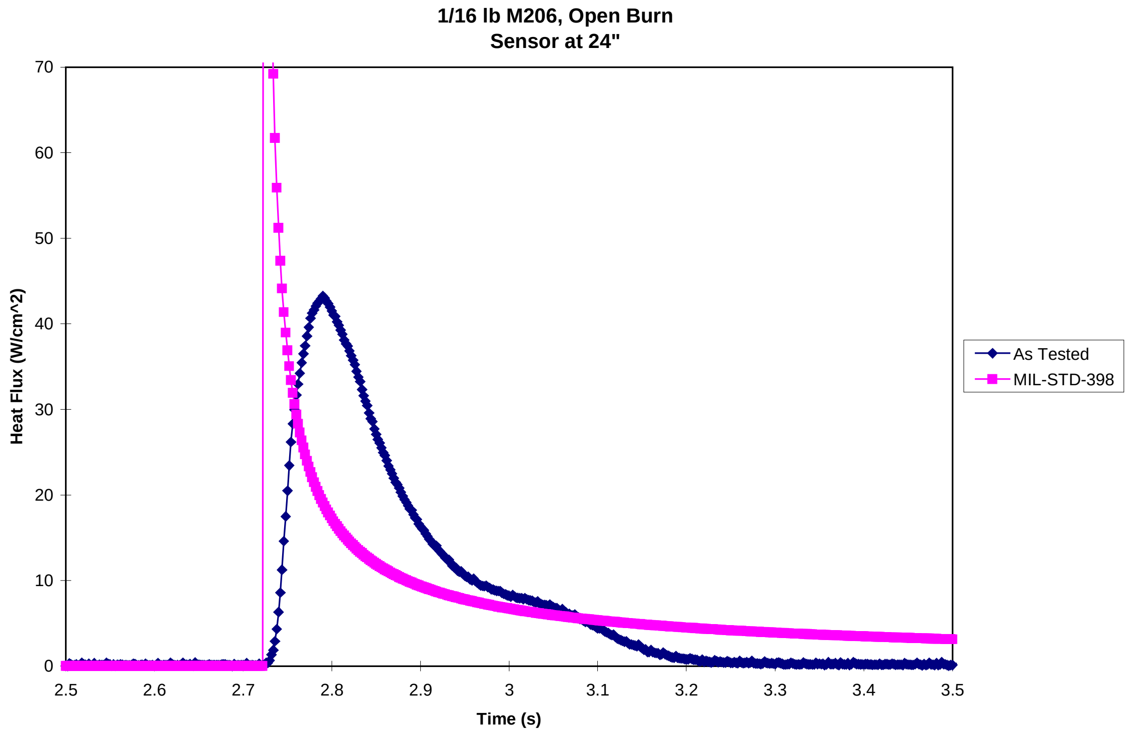
Graph II-17: 1/16# Green Smoke Open Burn



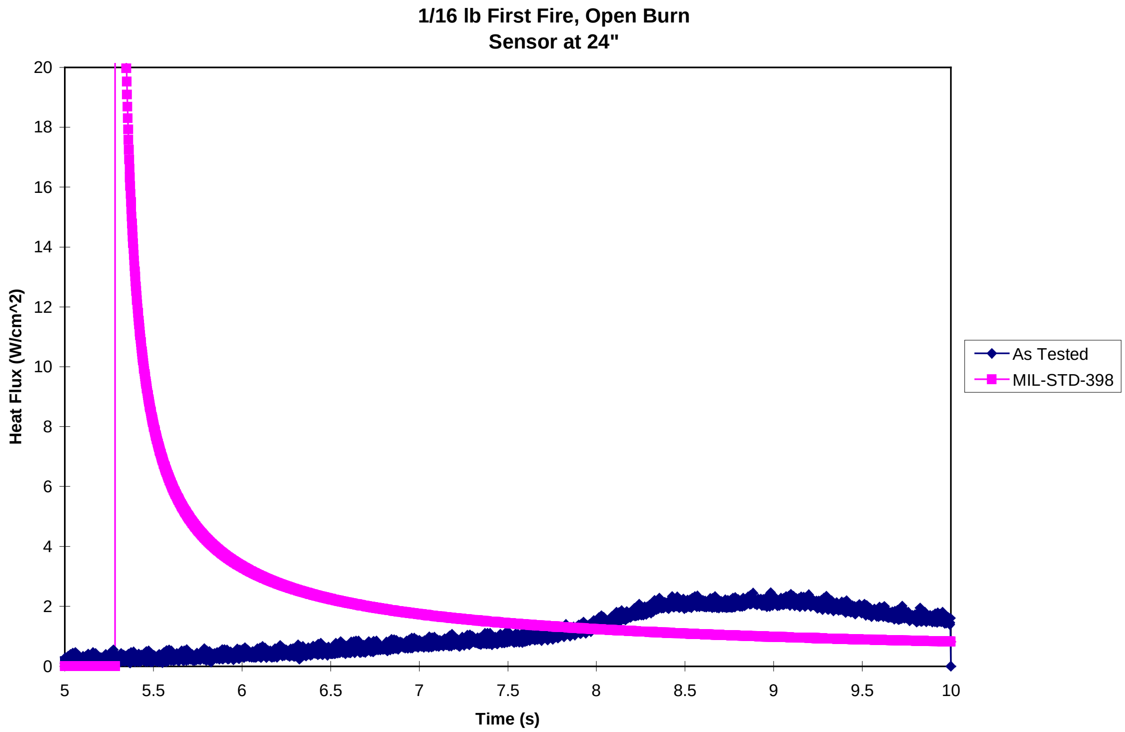
Graph II-18: 1/16# Yellow Smoke Open Burn



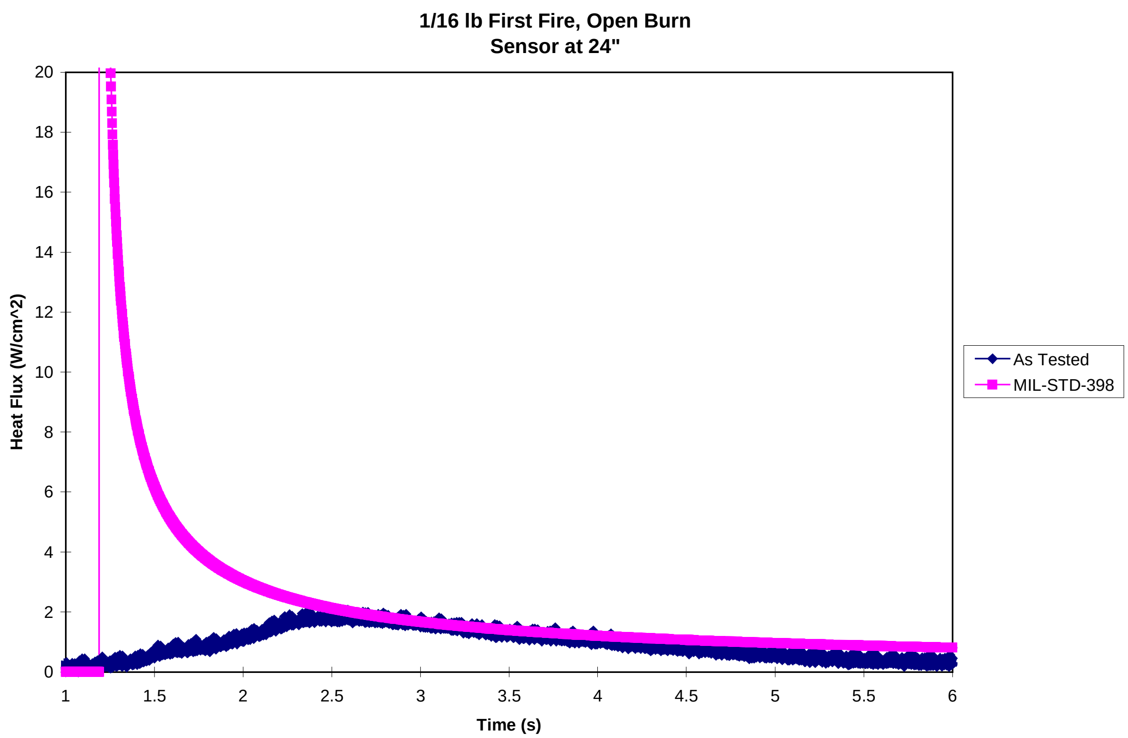
Graph II-19: 1/16# M206 Open Burn



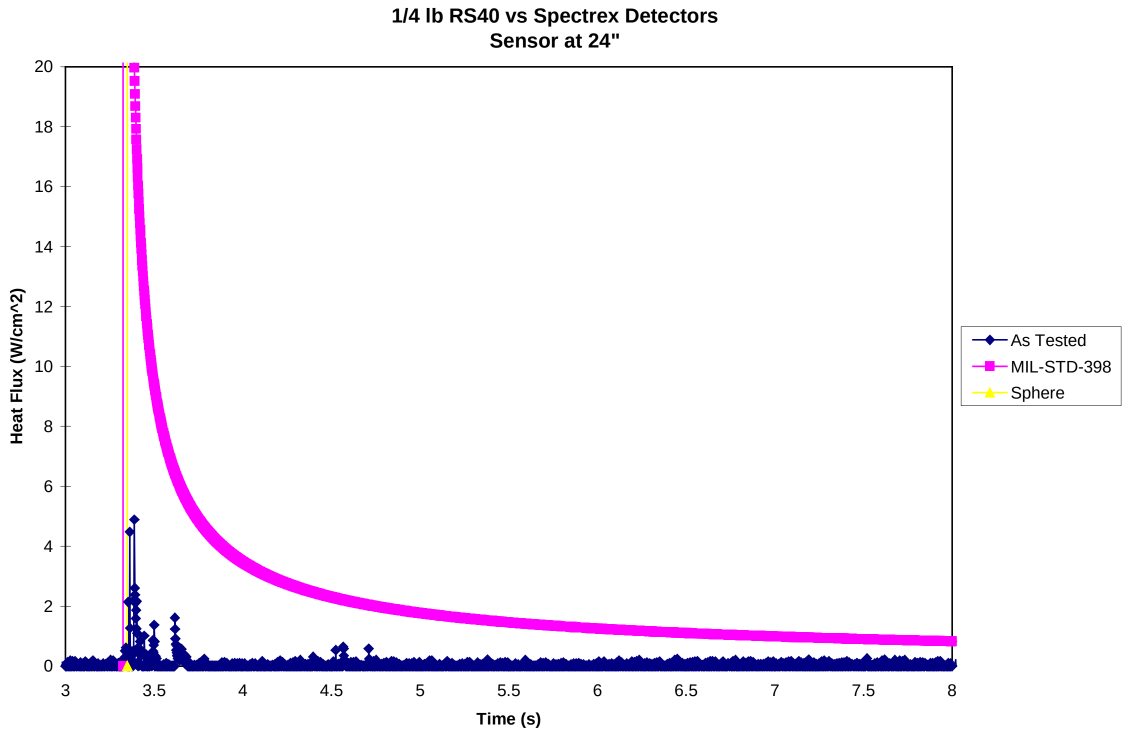
Graph II-20: 1/16# M206 Open Burn



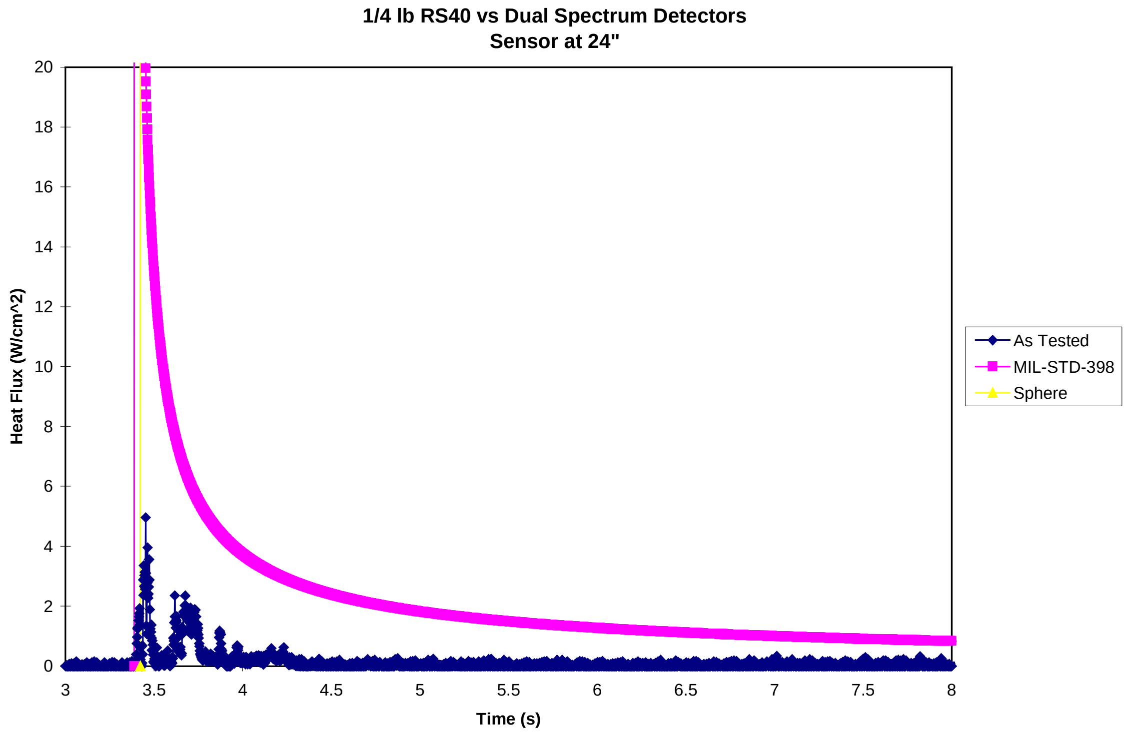
Graph II-21: 1/16# First Fire Open Burn



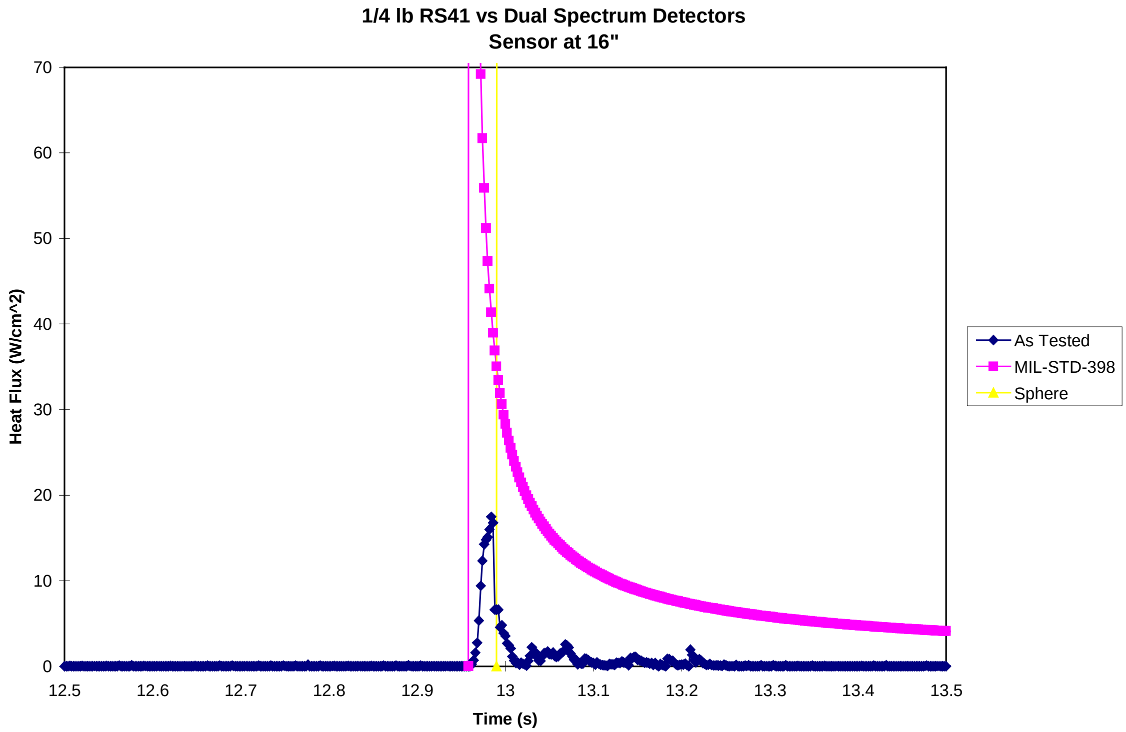
Graph II-22: 1/16# First Fire Open Burn



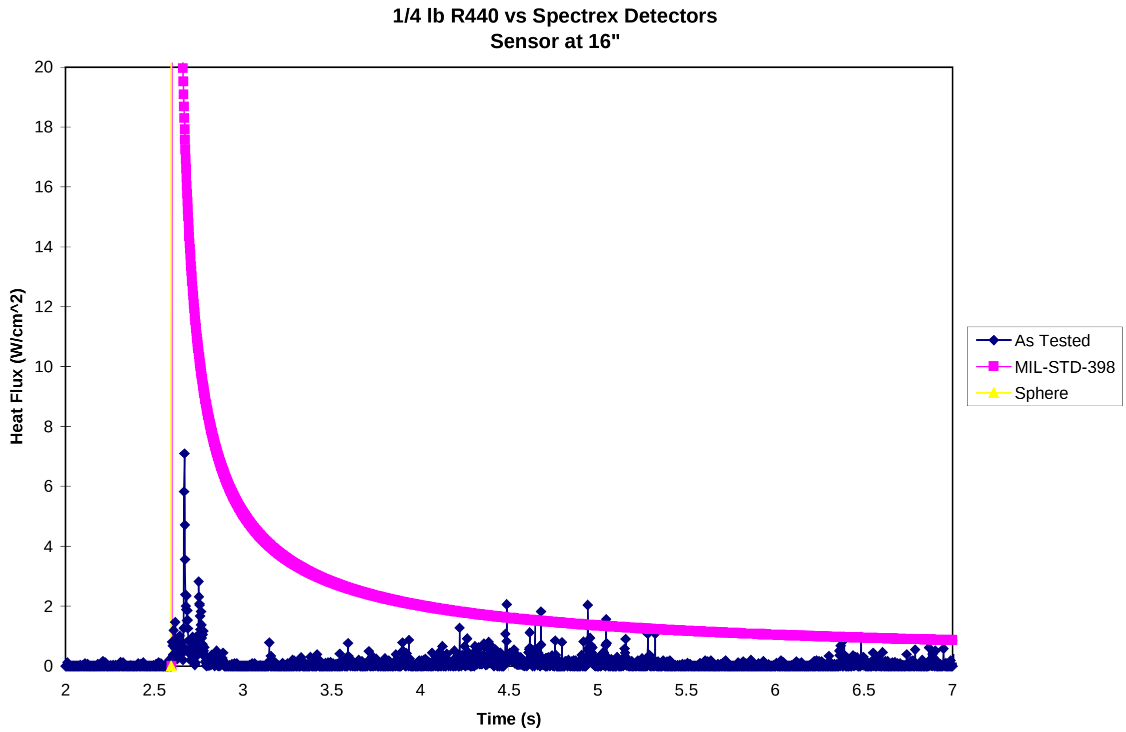
Graph II-23: ¼# RS-40 vs Spectrex Detectors - Flux Sensor @ 24"



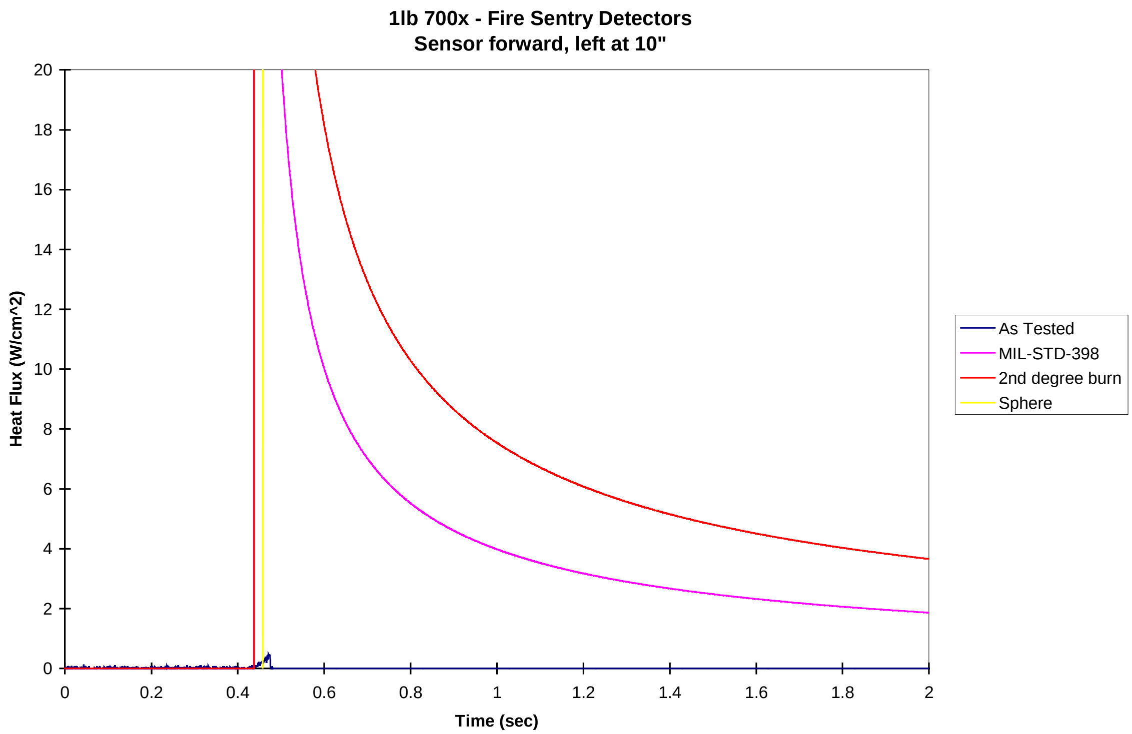
Graph II-24: ¼# RS-40 vs Dual Spectrum Detectors - Flux Sensor @ 24"



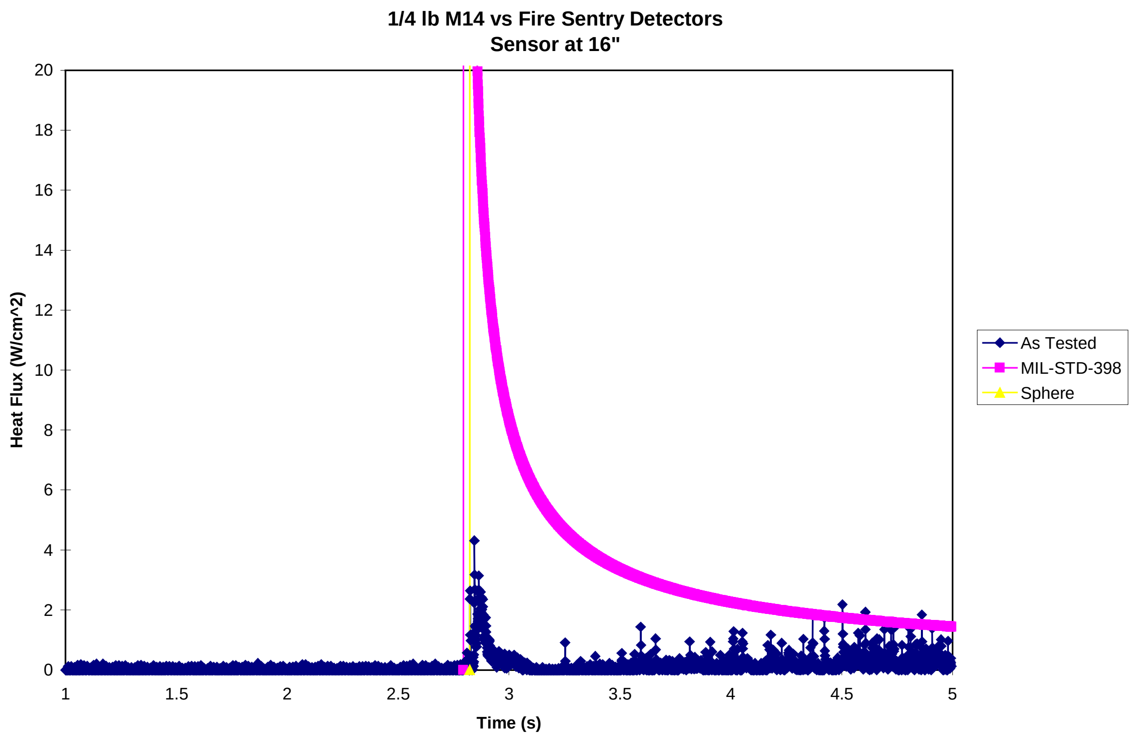
Graph II-25: ¼# RS-41 vs Dual Spectrum Detectors - Flux Sensor @ 16"



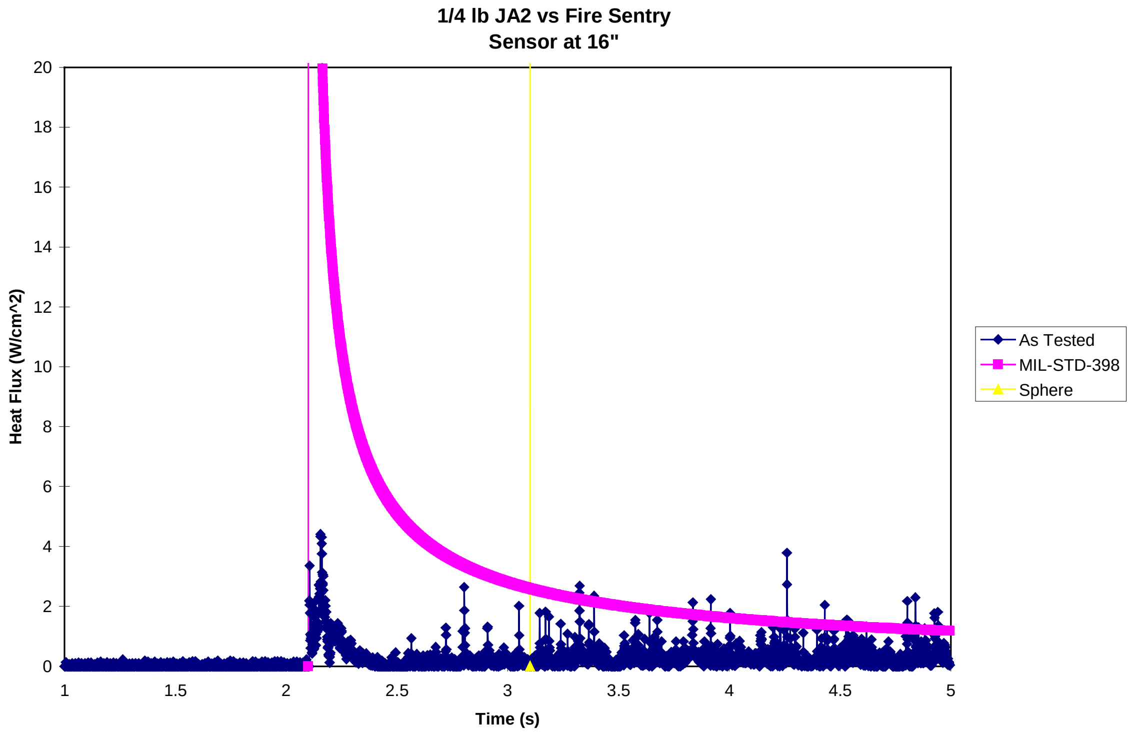
Graph II-26: ¼# R440 vs Spectrex Detectors- Flux Sensor @ 16"



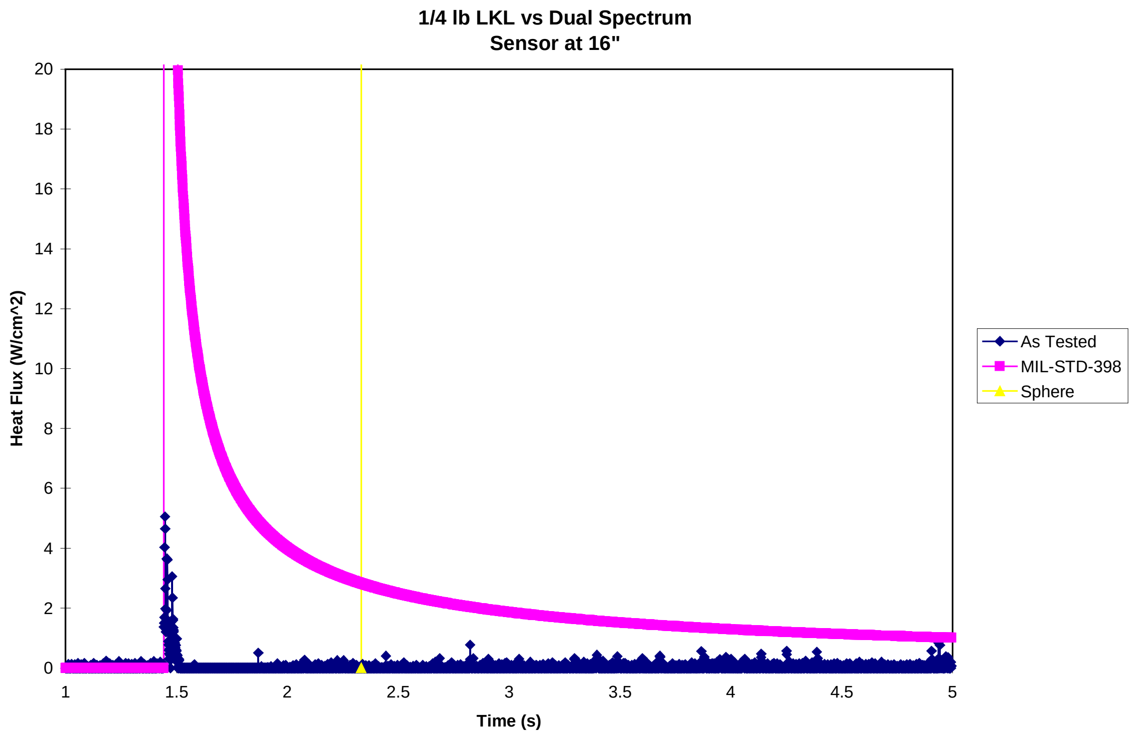
Graph II-27: 1# Hy-Skor 700X vs Fire Sentry Detectors - Flux Sensor @ 10”



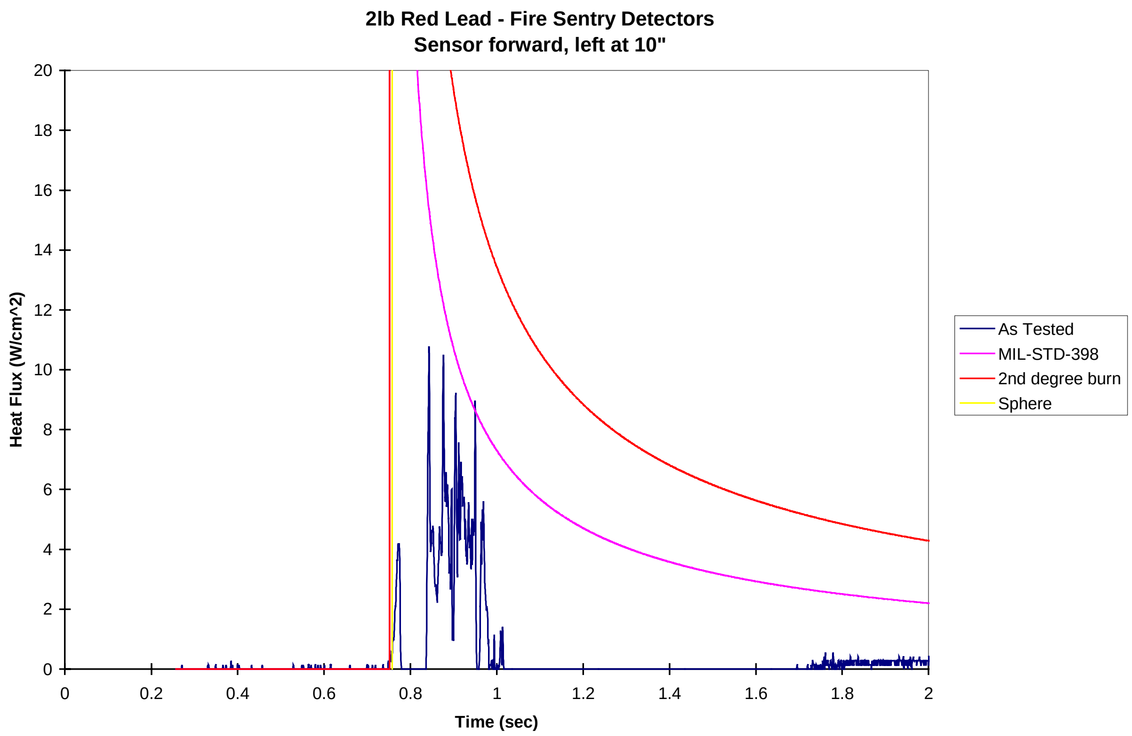
Graph II-28: ¼# M14 vs Fire Sentry Detectors- Flux Sensor @ 16”



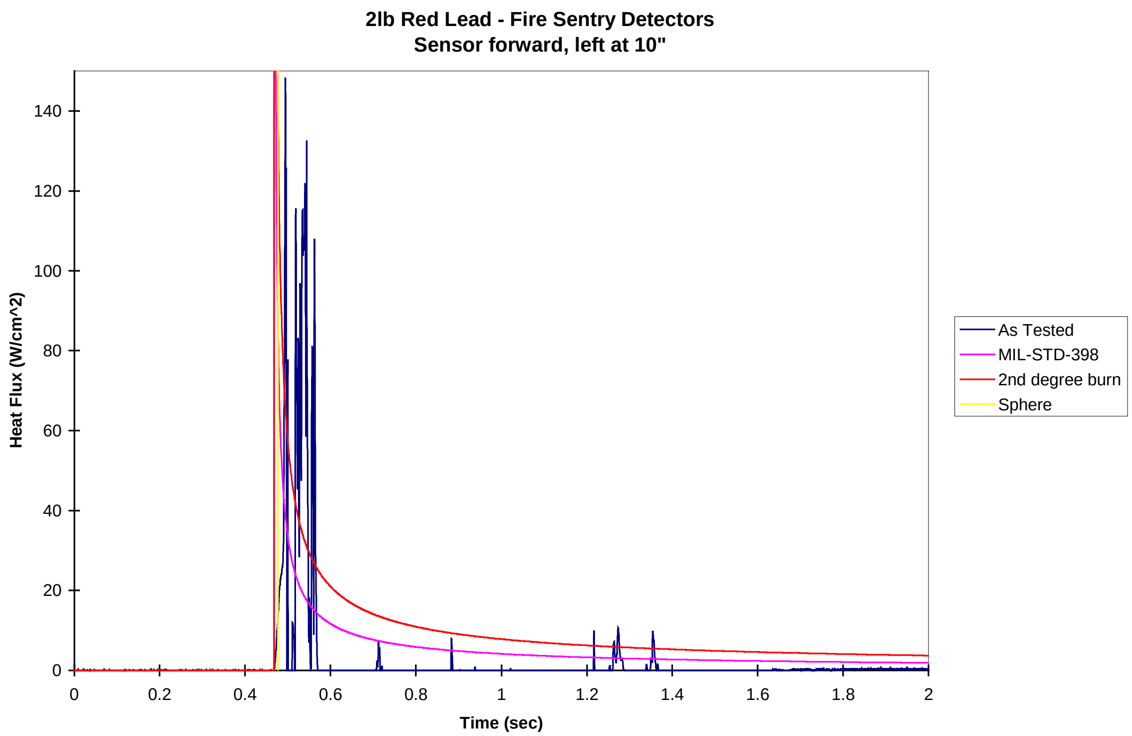
Graph II-29: ¼# JA2 vs Fire Sentry Detectors- Flux Sensor @ 16”



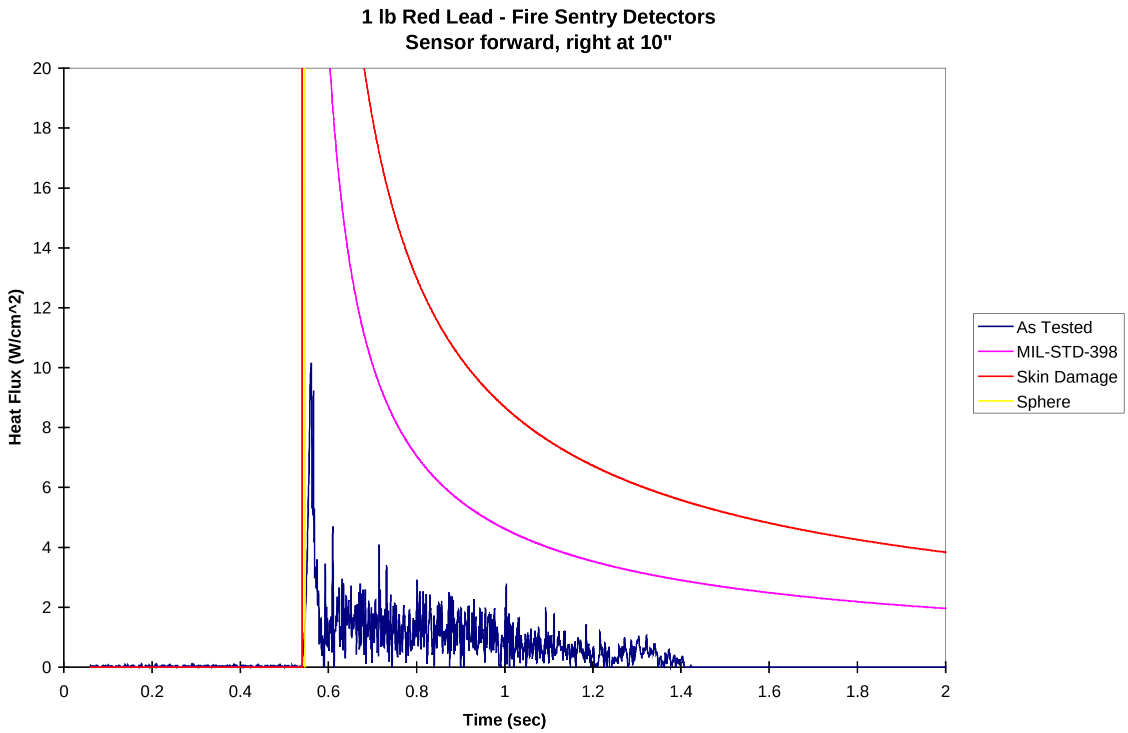
Graph II-30: ¼# LKL vs Dual Spectrum Detectors - Flux Sensor @ 16”



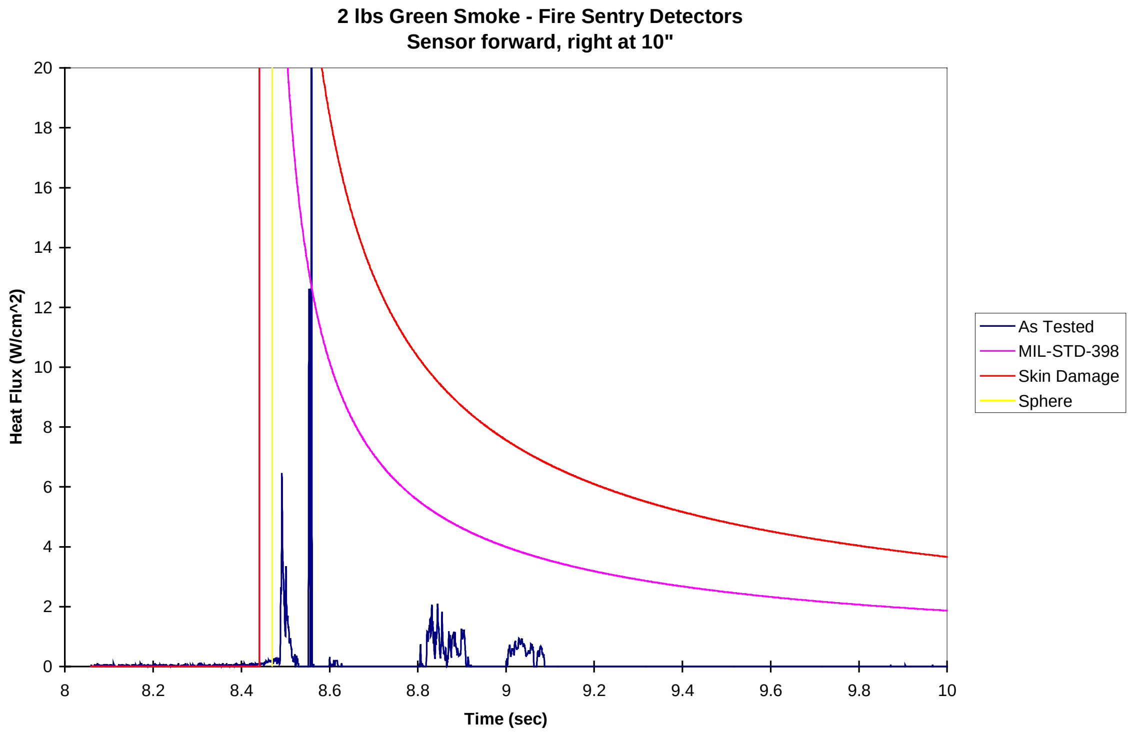
Graph II-31: 2# Red Lead vs Fire Sentry Detectors- Flux Sensor @ 10"



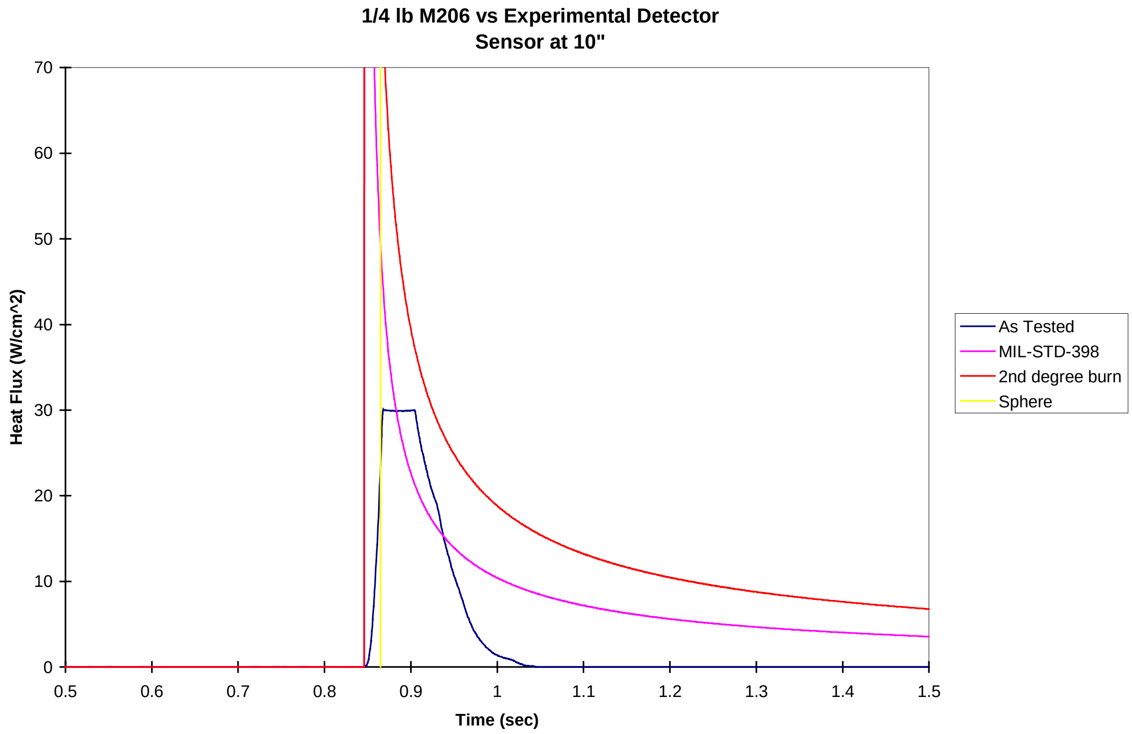
Graph II-32: 2# Red Lead vs Fire Sentry Detectors - Flux Sensor @ 10"



Graph II-33: 1# Red Lead vs Fire Sentry Detectors - Flux Sensor @ 10”



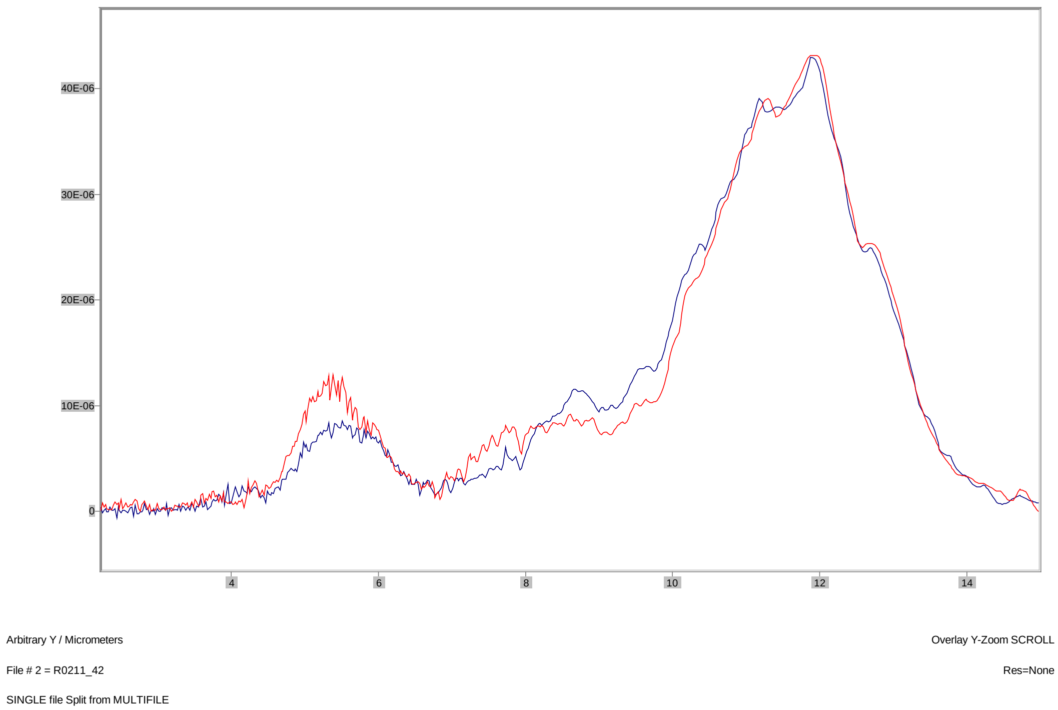
Graph II-34: 2# Green Smoke vs Fire Sentry Detectors - Flux Sensor @ 10”



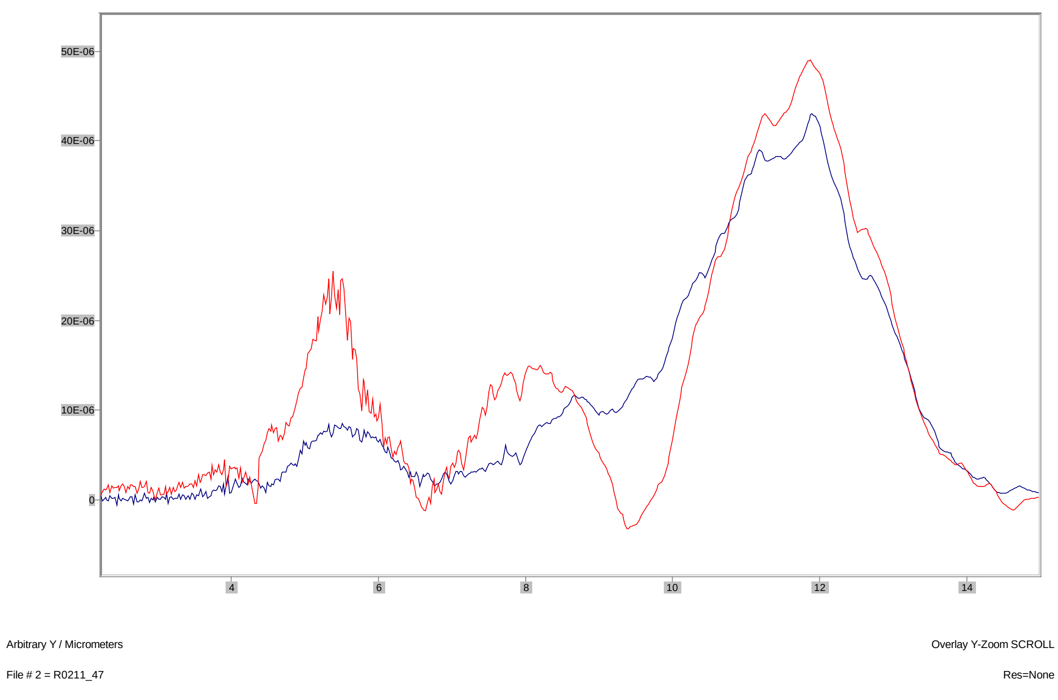
Graph II-35: 1/4# M206 vs Experimental Detector - Flux Sensor @ 10”

APPENDIX III

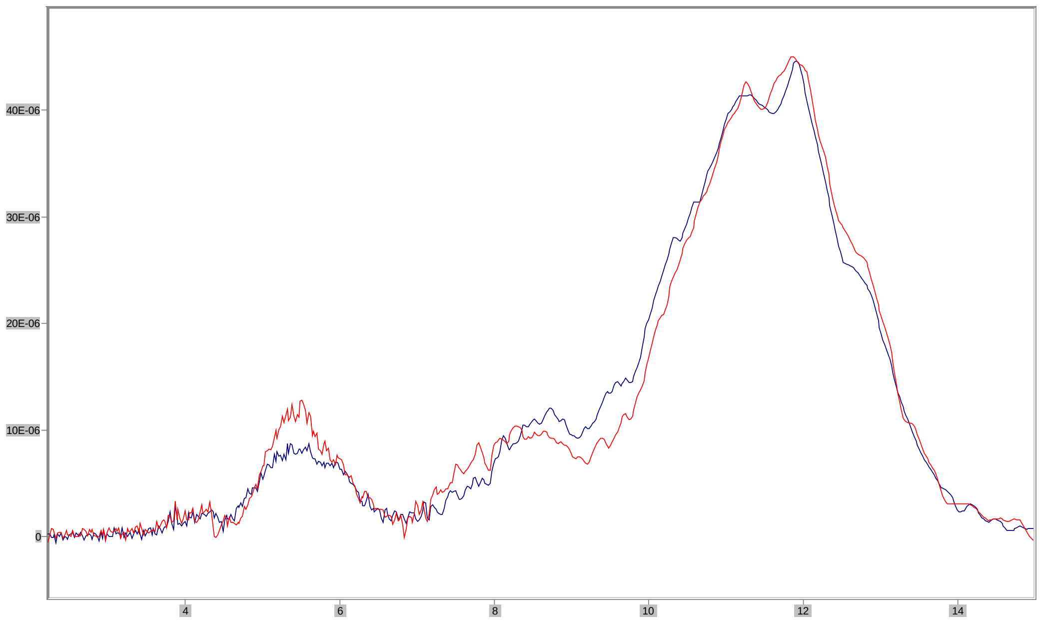
INFRARED SPECTRAL DATA



Graph III-1: RS-40 Open Burn IR Spectra



Graph III-2: RS-40 Open Burn IR Spectra



Arbitrary Y / Micrometers

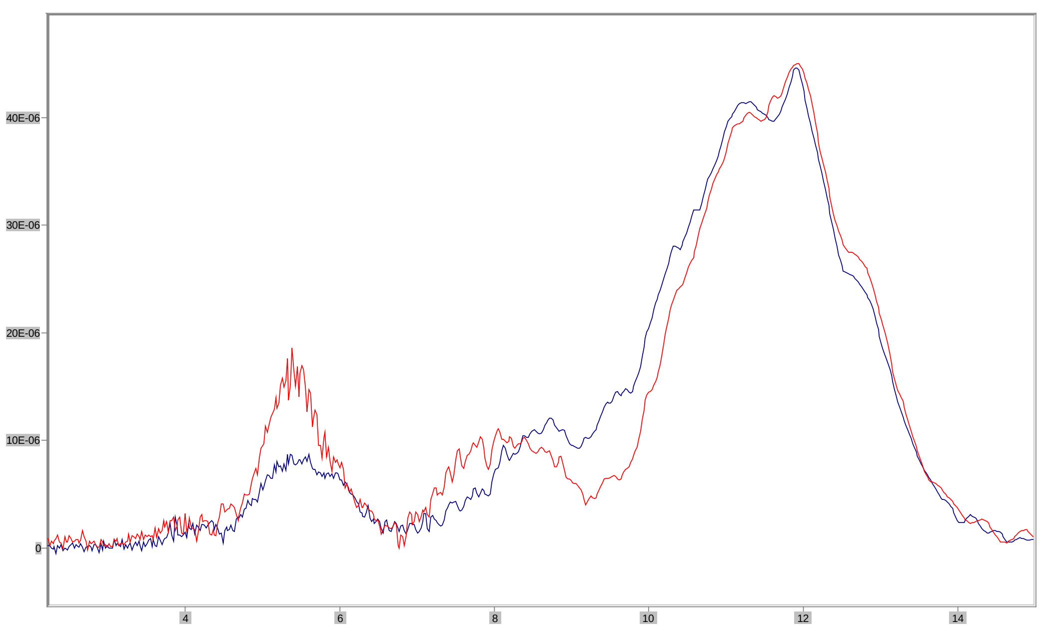
Overlay Y-Zoom SCROLL

File # 2 = R0212_42

Res=None

SINGLE file Split from MULTIFILE

Graph III-3: RS-40 Open Burn IR Spectra



Arbitrary Y / Micrometers

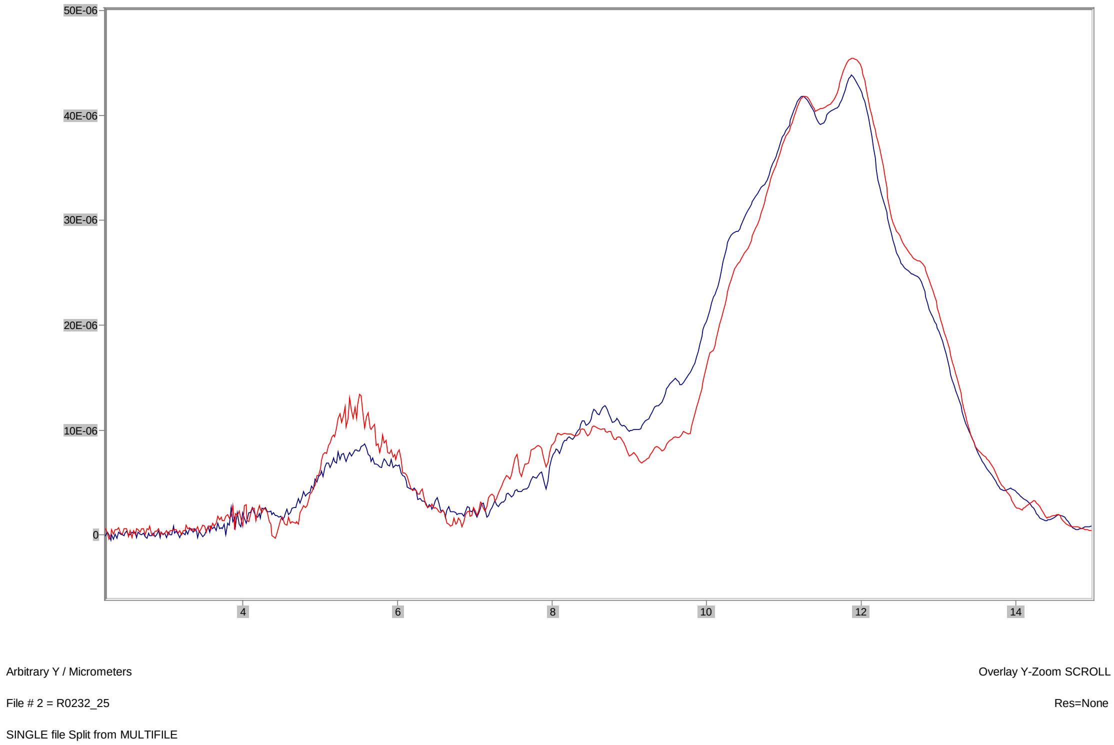
Overlay Y-Zoom SCROLL

File # 2 = R0212_44

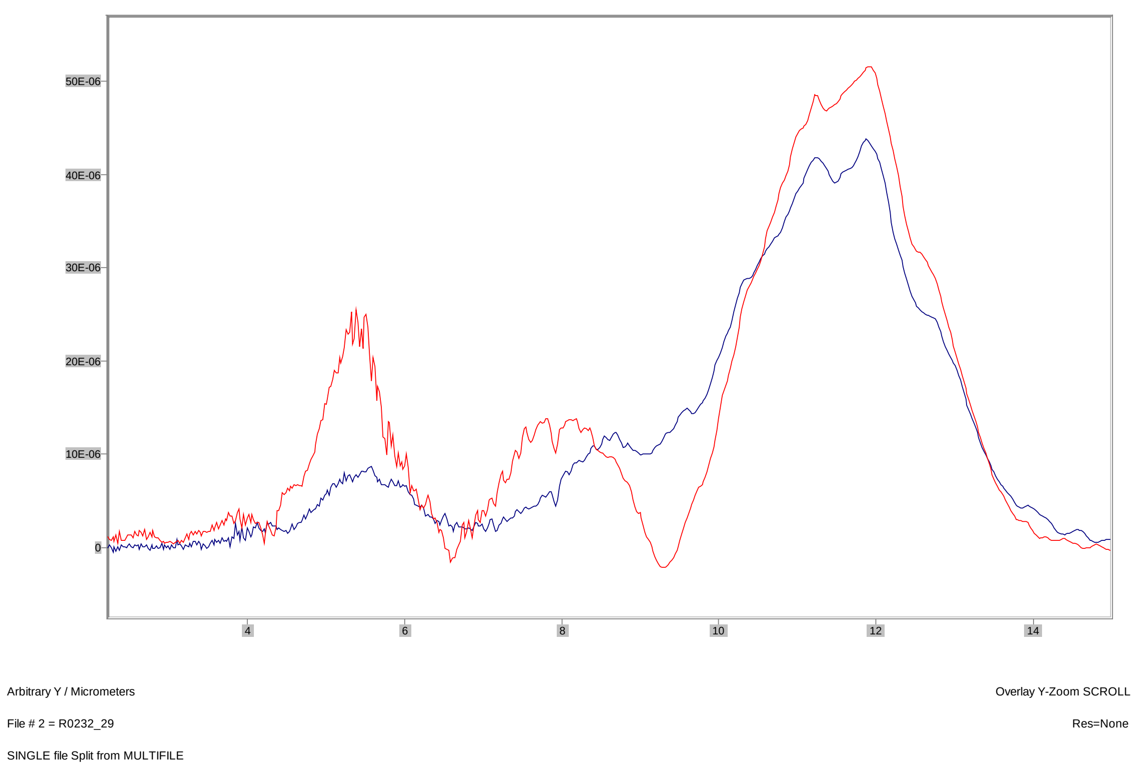
Res=None

SINGLE file Split from MULTIFILE

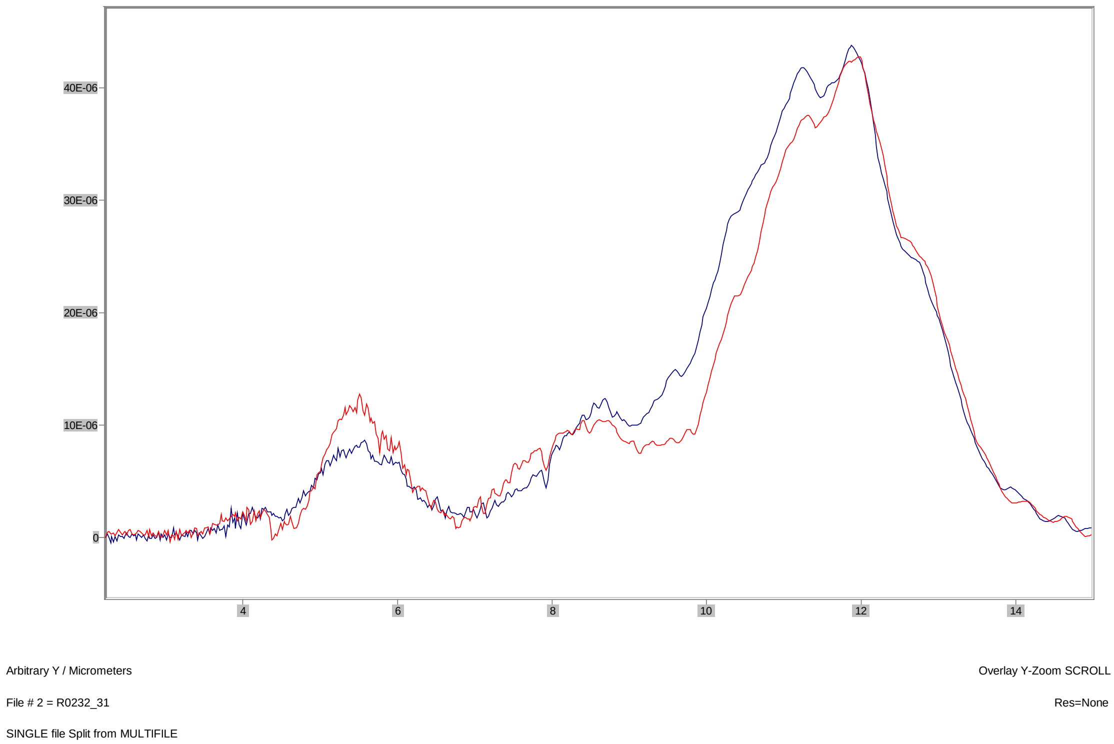
Graph III-4: RS-40 Open Burn IR Spectra



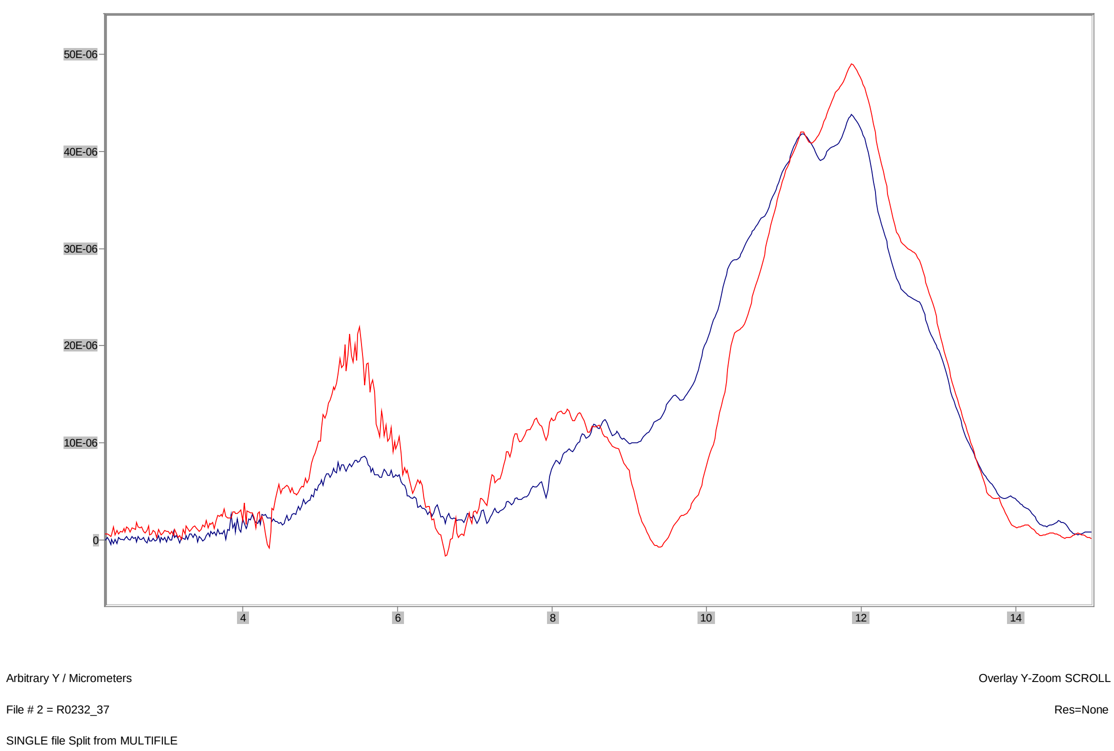
Graph III-5: RS-40 Open Burn IR Spectra



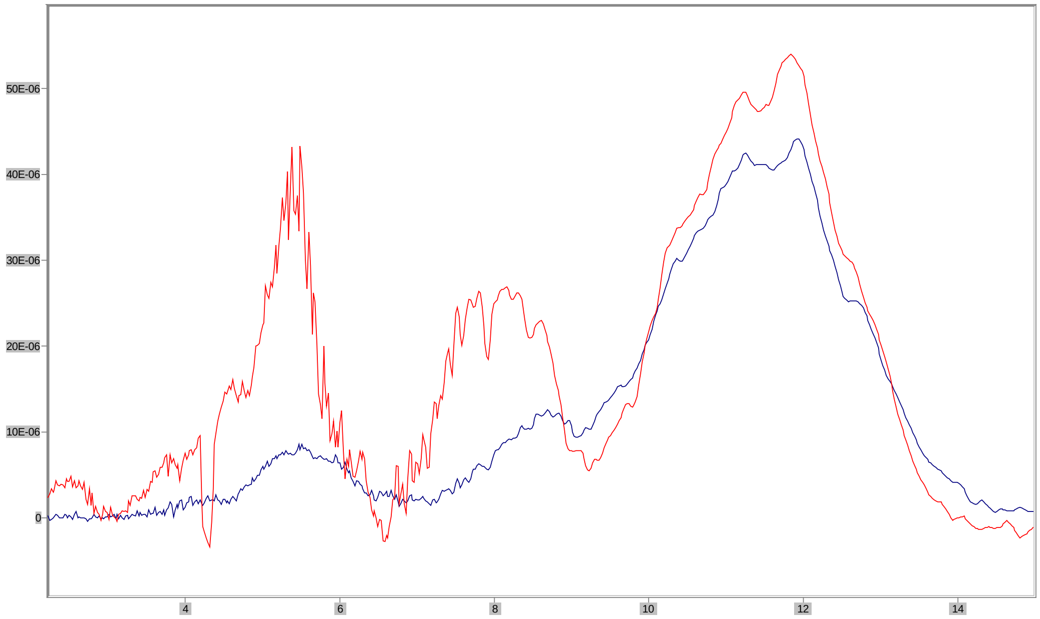
Graph III-6: RS-40 Open Burn IR Spectra



Graph III-7: RS-40 Open Burn IR Spectra



Graph III-8: RS-40 Open Burn IR Spectra



Arbitrary Y / Micrometers

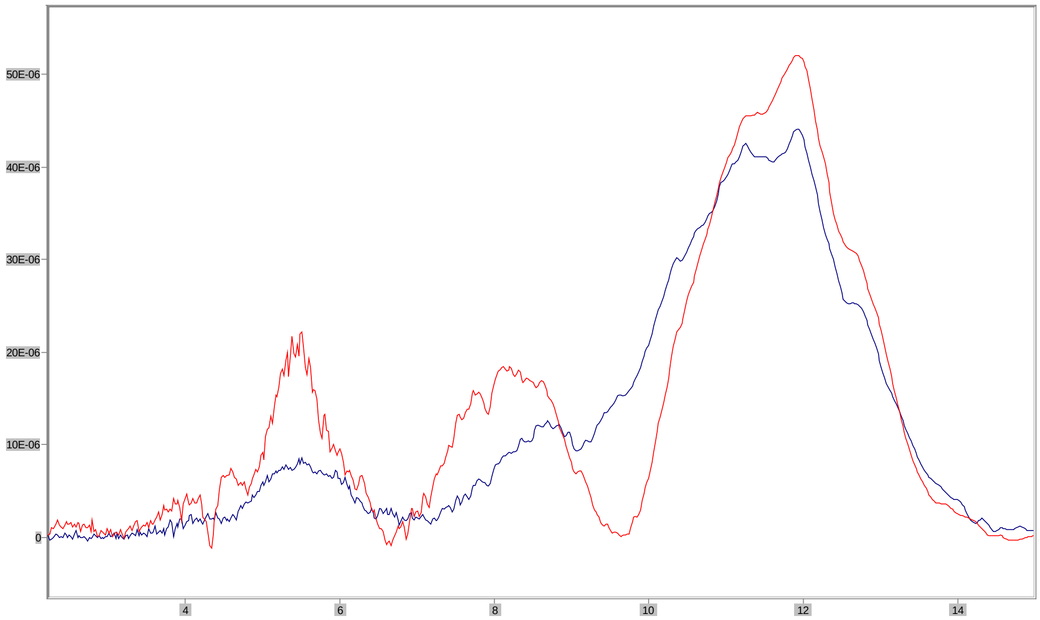
Overlay Y-Zoom SCROLL

File # 2 = R1213_69

Res=None

SINGLE file Split from MULTIFILE

Graph III-9: RS-41 Open Burn IR Spectra



Arbitrary Y / Micrometers

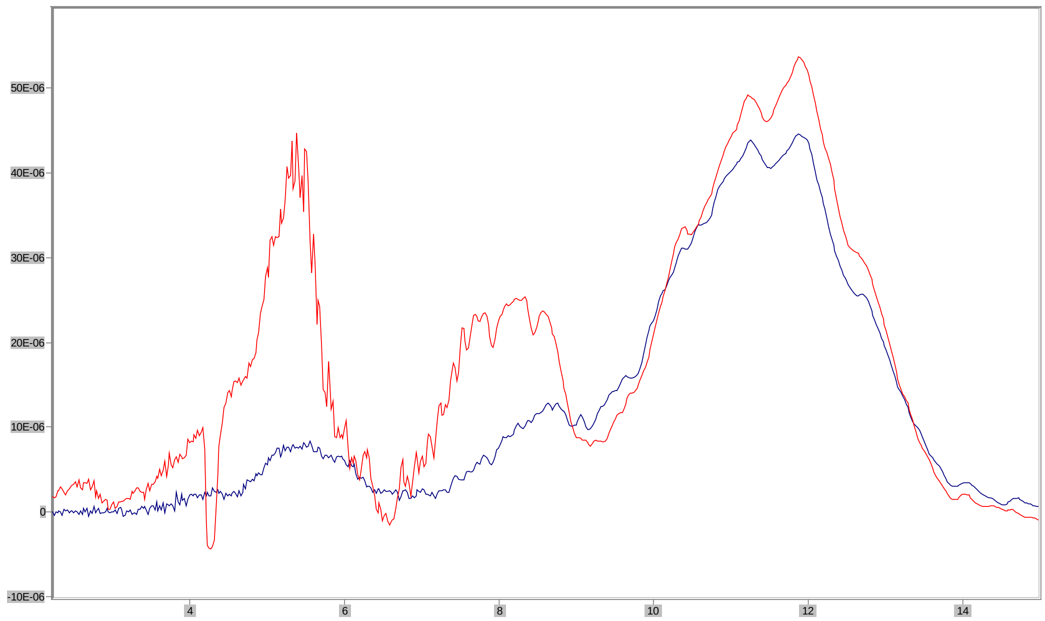
Overlay Y-Zoom SCROLL

File # 2 = R1213_70

Res=None

SINGLE file Split from MULTIFILE

Graph III-10: RS-41 Open Burn IR Spectra



Arbitrary Y / Micrometers

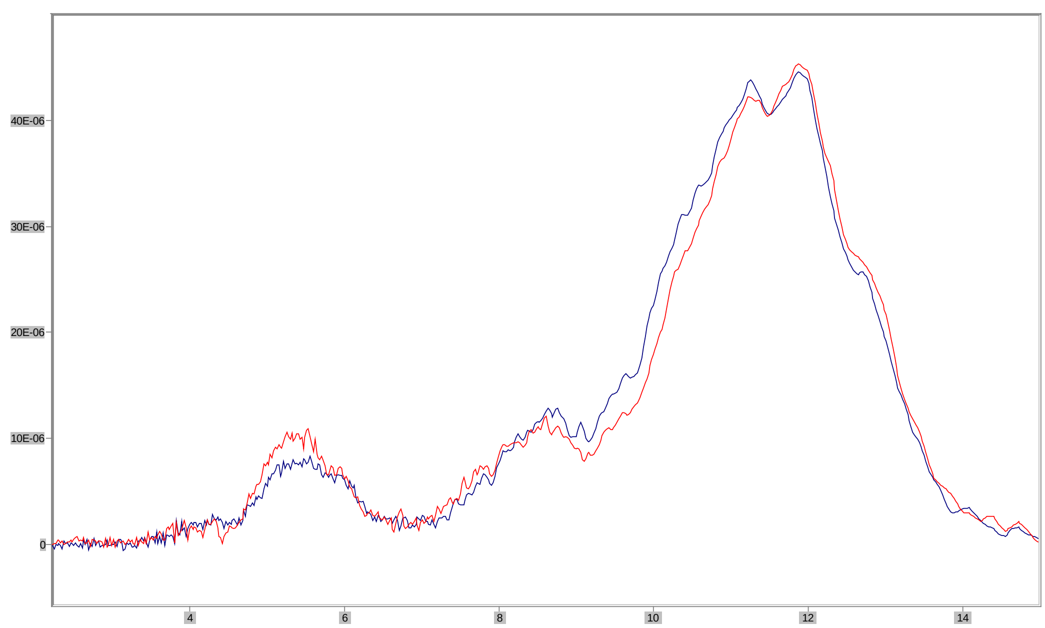
Overlay Y-Zoom SCROLL

File # 2 = R1214_18

Res=None

SINGLE file Split from MULTIFILE

Graph III-11: RS-41 Open Burn IR Spectra



Arbitrary Y / Micrometers

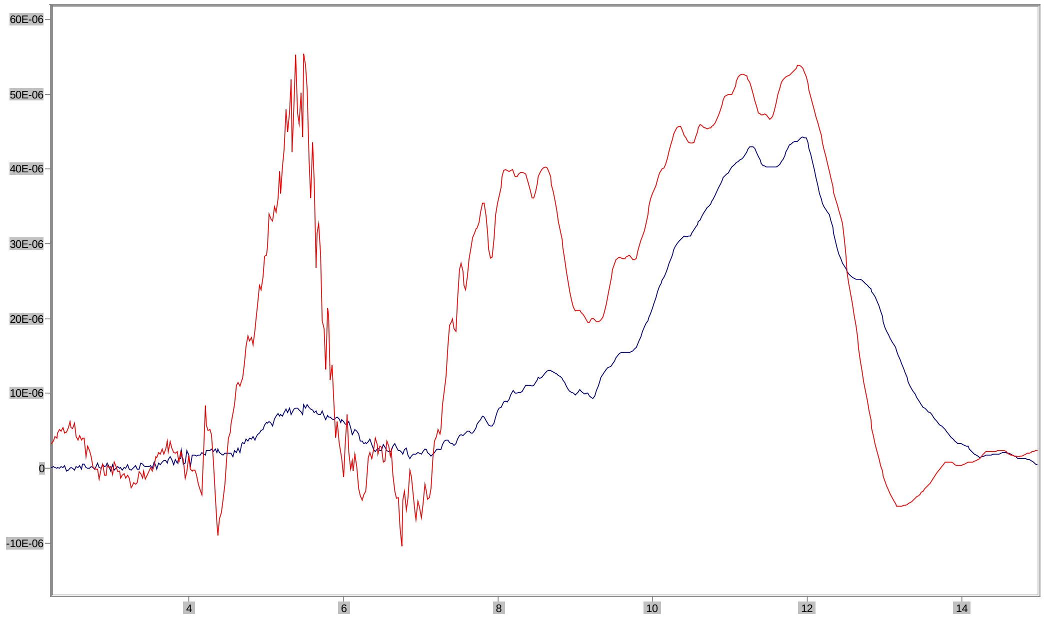
Overlay Y-Zoom SCROLL

File # 2 = R1214_19

Res=None

SINGLE file Split from MULTIFILE

Graph III-12: RS-41 Open Burn IR Spectra

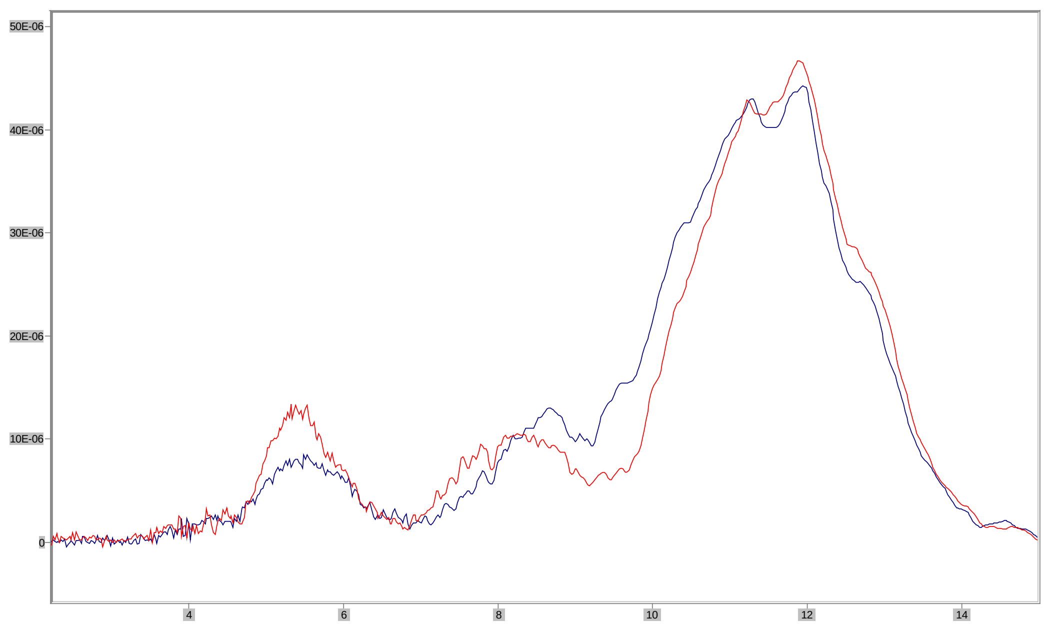


Arbitrary Y / Micrometers
Overlay Y-Zoom SCROLL

File # 2 = R1233_27
Res=None

SINGLE file Split from MULTIFILE

Graph III-13: RS-41 Open Burn IR Spectra

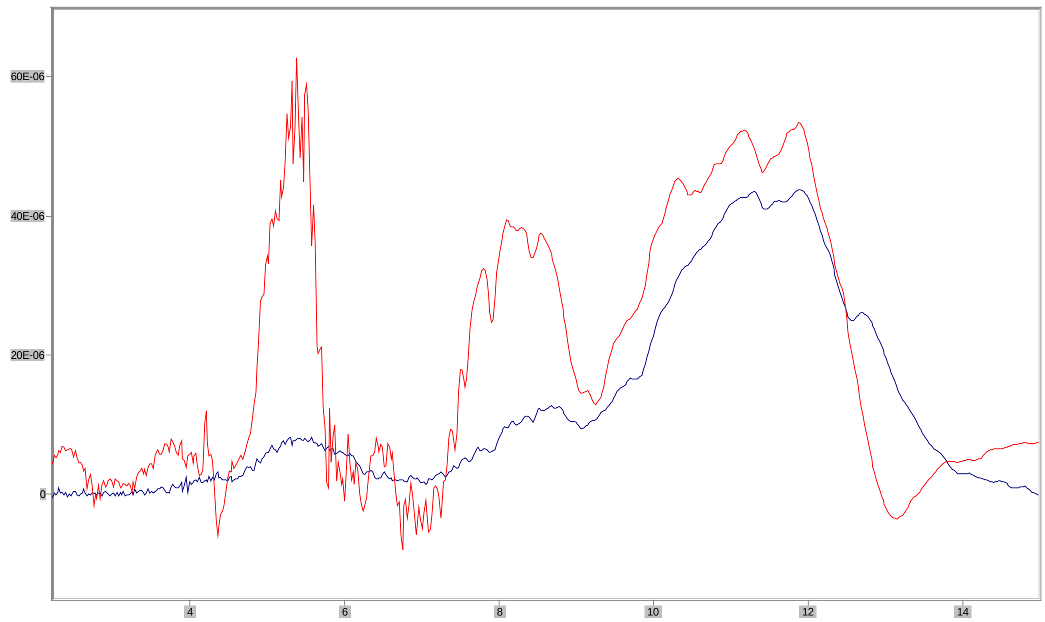


Arbitrary Y / Micrometers
Overlay Y-Zoom SCROLL

File # 2 = R1233_28
Res=None

SINGLE file Split from MULTIFILE

Graph III-14: RS-41 Open Burn IR Spectra



Arbitrary Y / Micrometers

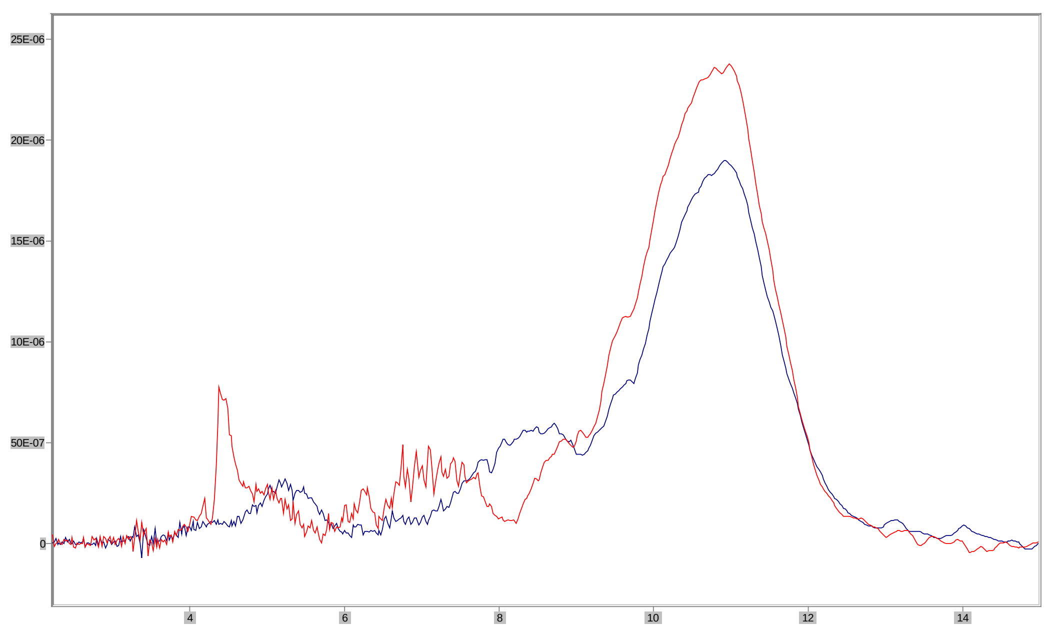
Overlay Y-Zoom SCROLL

File # 2 = R1234_35

Res=None

SINGLE file Split from MULTIFILE

Graph III-15: RS-41 Open Burn IR Spectra



Arbitrary Y / Micrometers

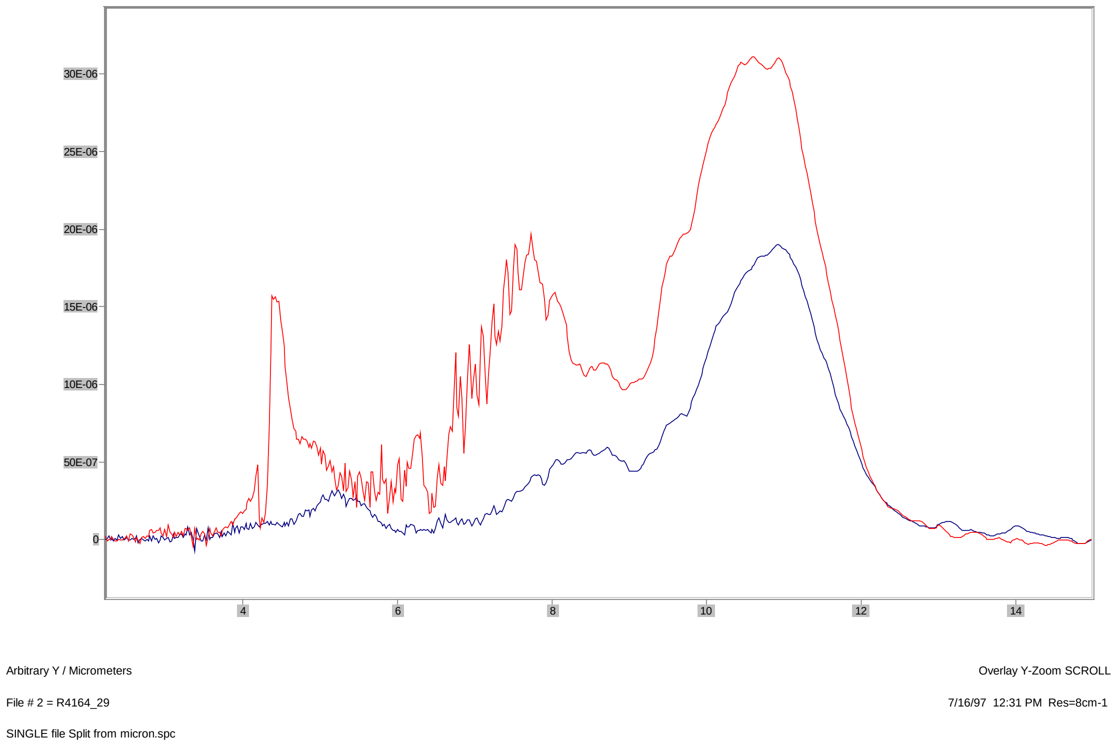
Overlay Y-Zoom SCROLL

File # 2 = R4164_26

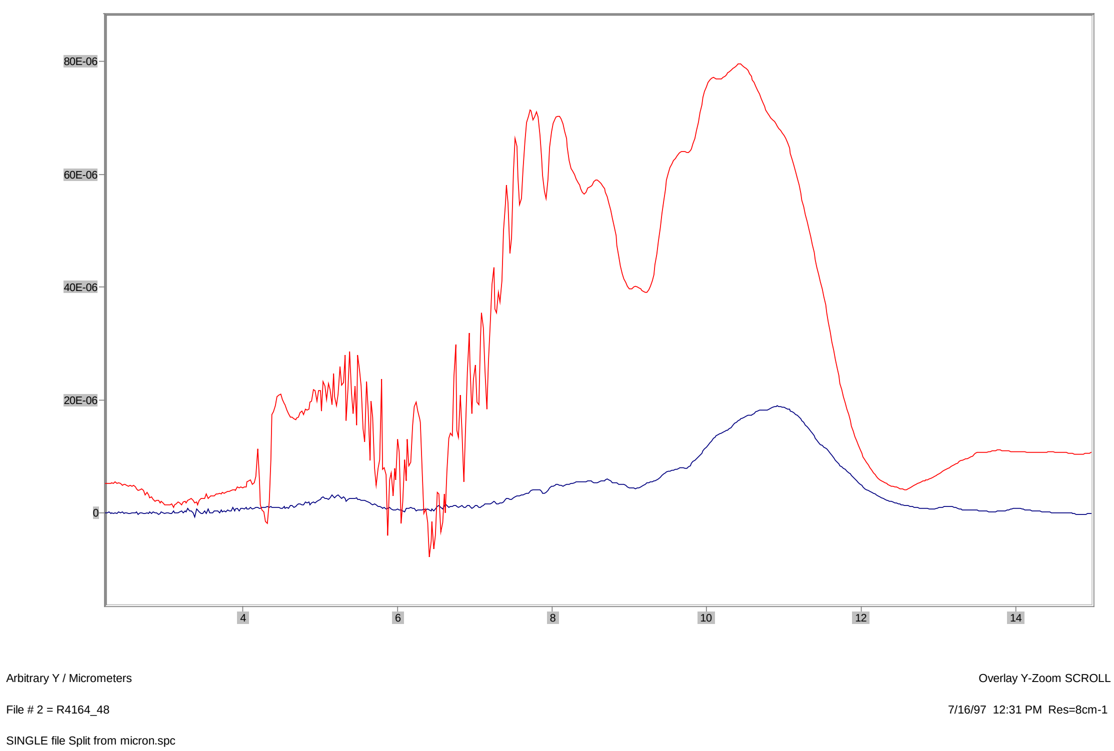
7/16/97 12:31 PM Res=8cm-1

SINGLE file Split from micron.spc

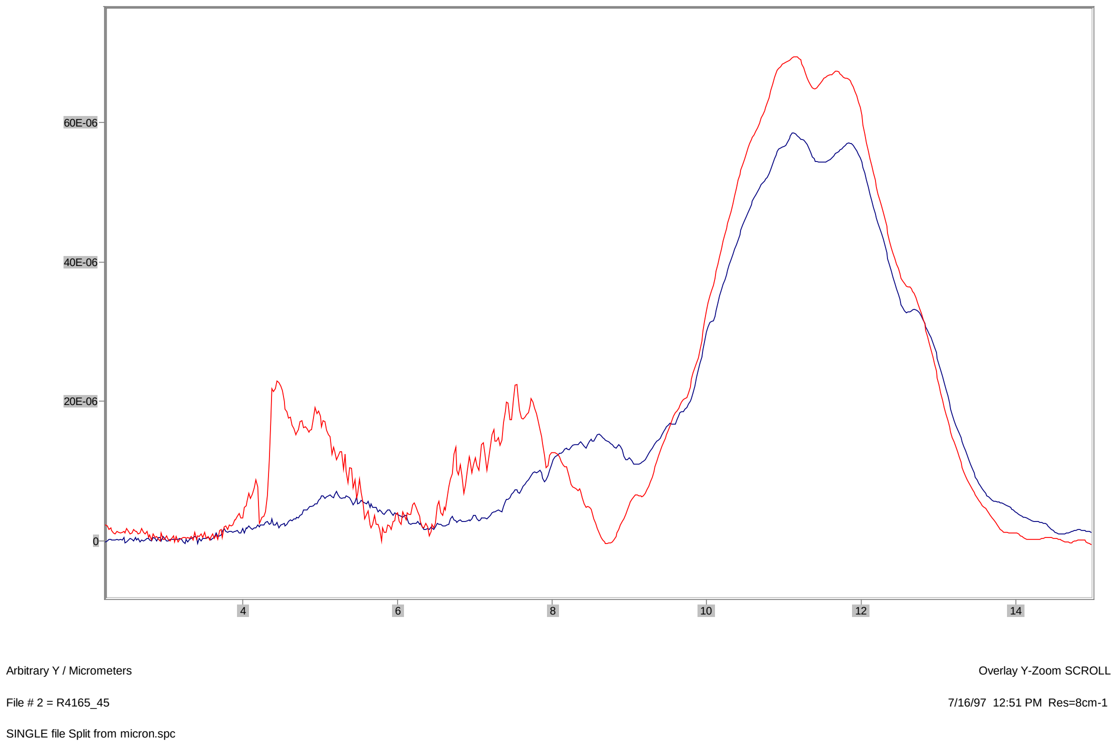
Graph III-16: R440 Open Burn IR Spectra



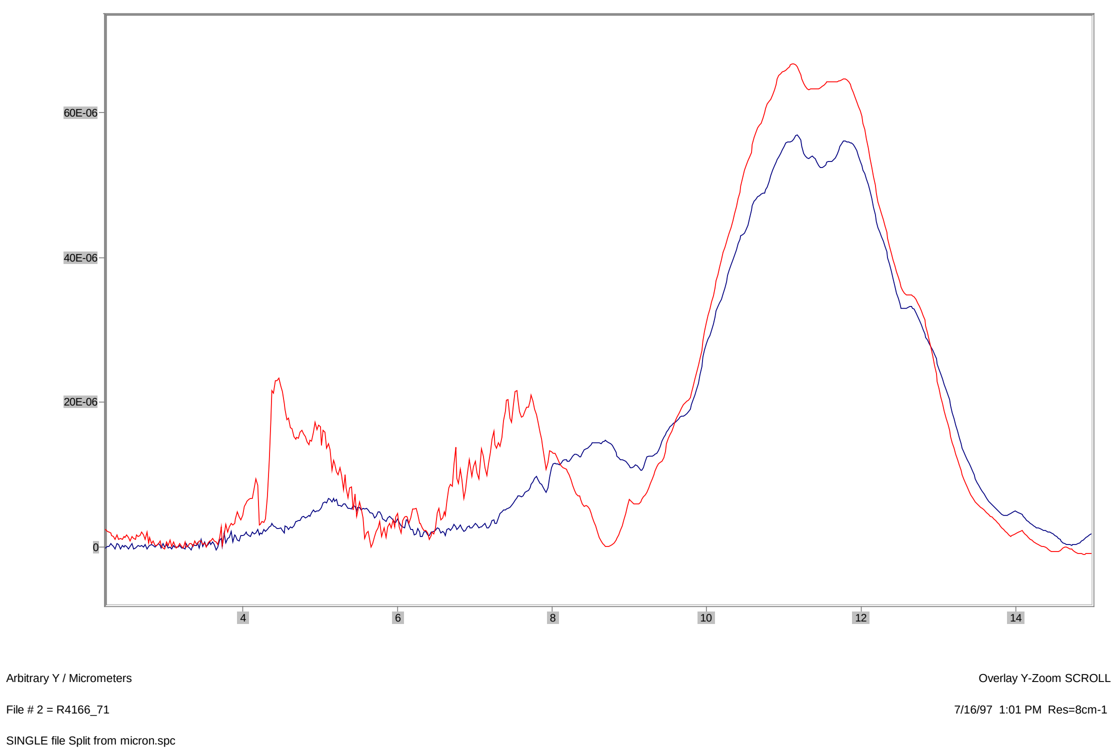
Graph III-17: R440 Open Burn IR Spectra



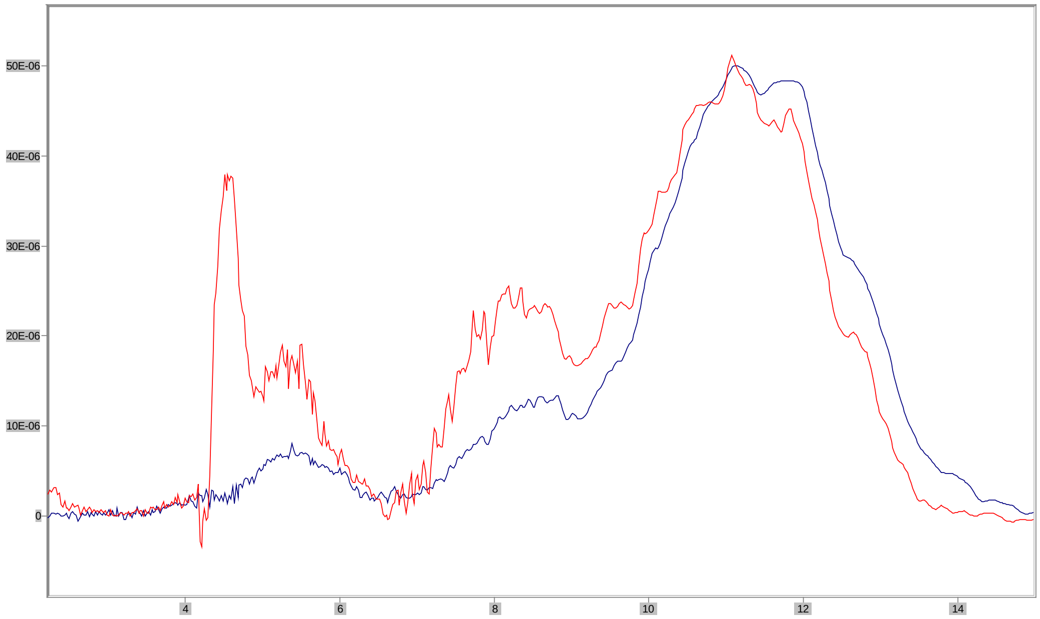
Graph III-18: R440 Open Burn IR Spectra



Graph III-19: R440 Open Burn IR Spectra



Graph III-20: R440 Open Burn IR Spectra



Arbitrary Y / Micrometers

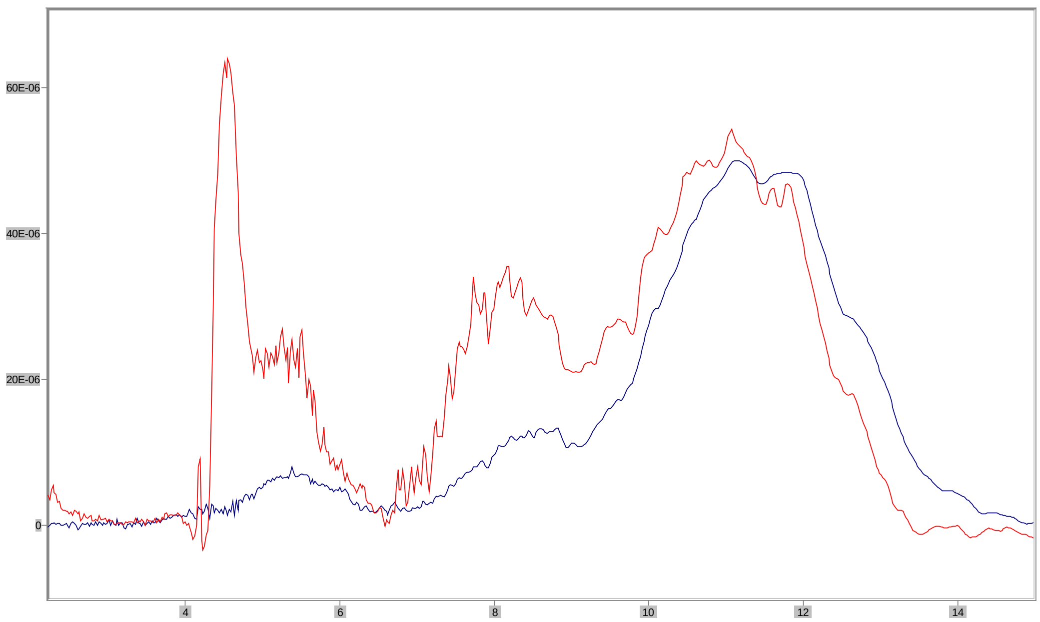
Overlay Y-Zoom SCROLL

File # 2 = HS214_8

7/2/97 1:53 PM Res=8cm-1

SINGLE file Split from micron.spc

Graph III-21: Hy-Skor 700X Open Burn IR Spectra



Arbitrary Y / Micrometers

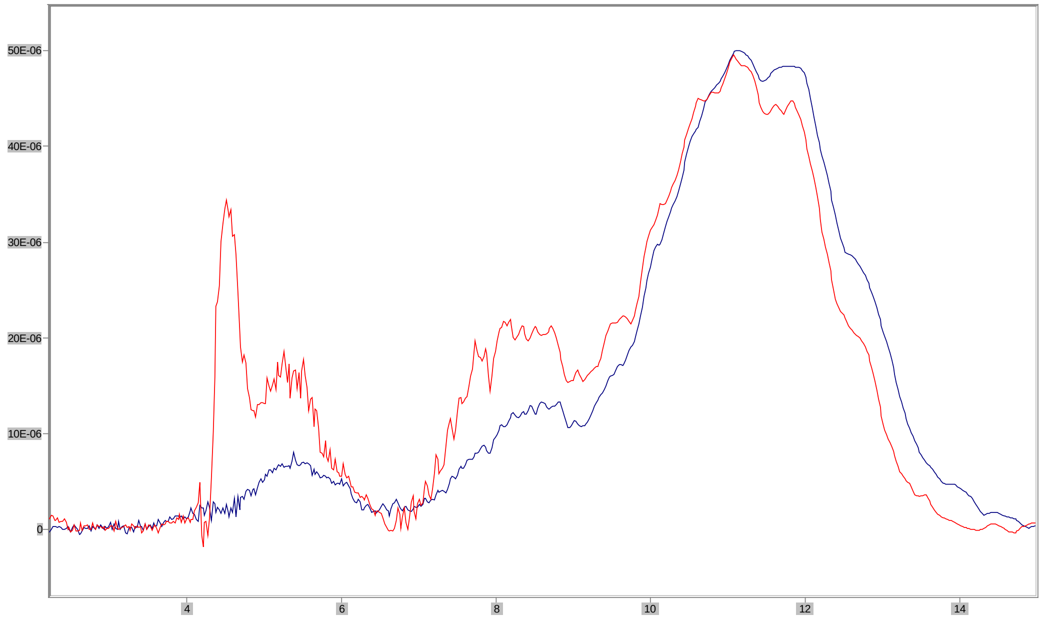
Overlay Y-Zoom SCROLL

File # 2 = HS214_11

7/2/97 1:53 PM Res=8cm-1

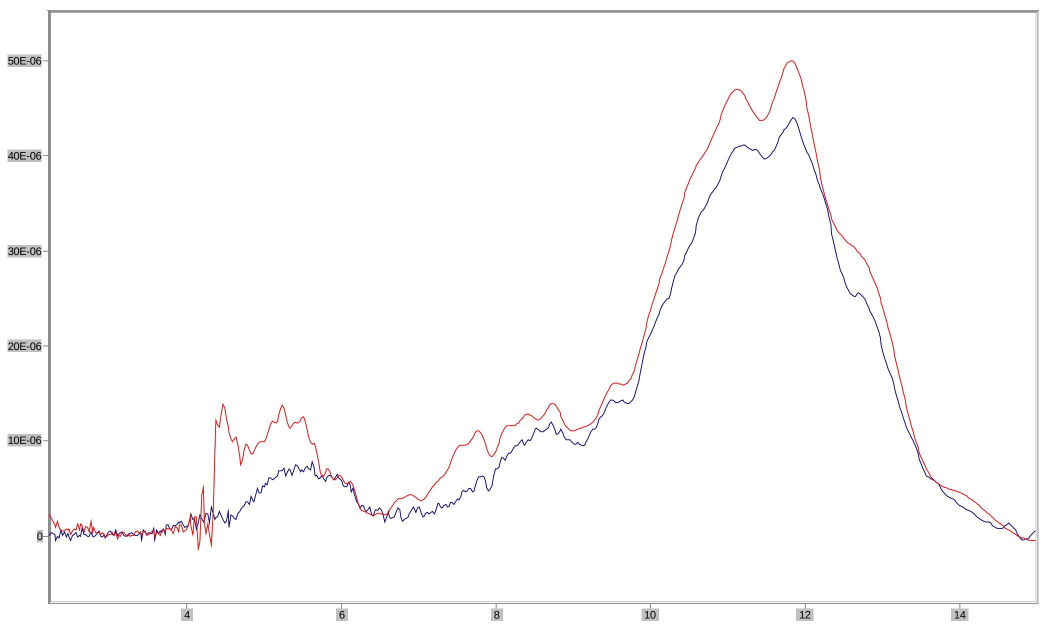
SINGLE file Split from micron.spc

Graph III-22: Hy-Skor 700X Open Burn IR Spectra



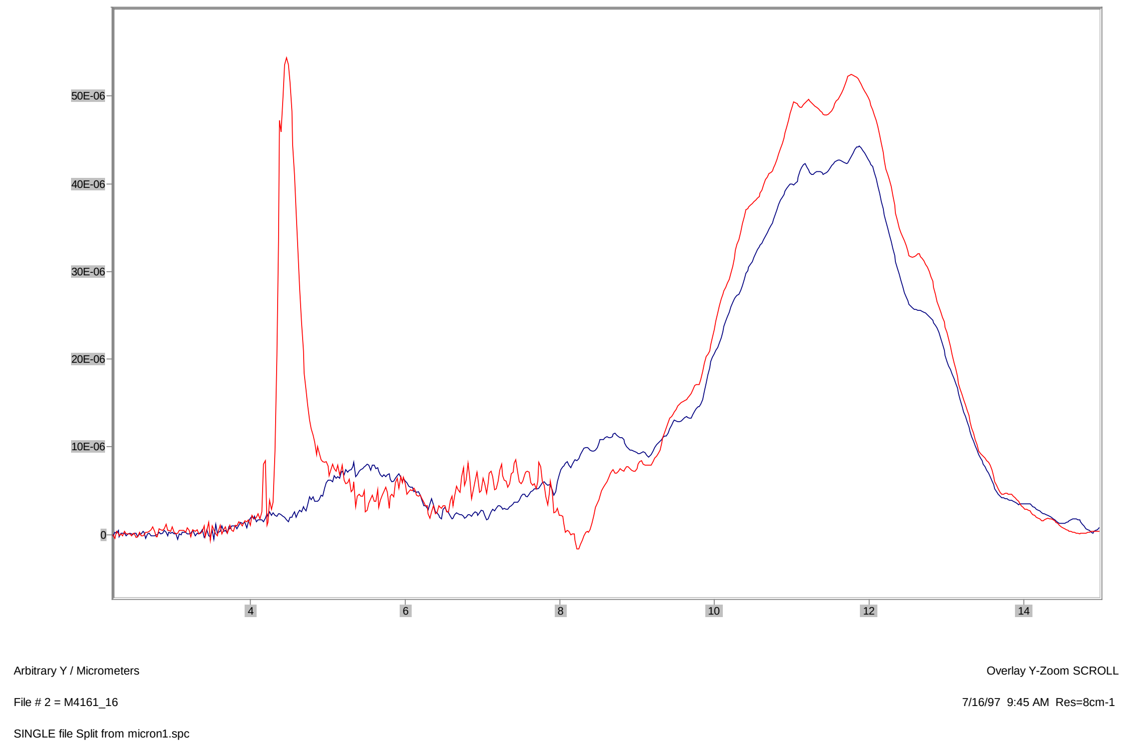
Arbitrary Y / Micrometers
Overlay Y-Zoom SCROLL
File # 2 = HS214_12
7/2/97 1:53 PM Res=8cm-1
SINGLE file Split from micron.spc

Graph III-23: Hy-Skor 700X Open Burn IR Spectra

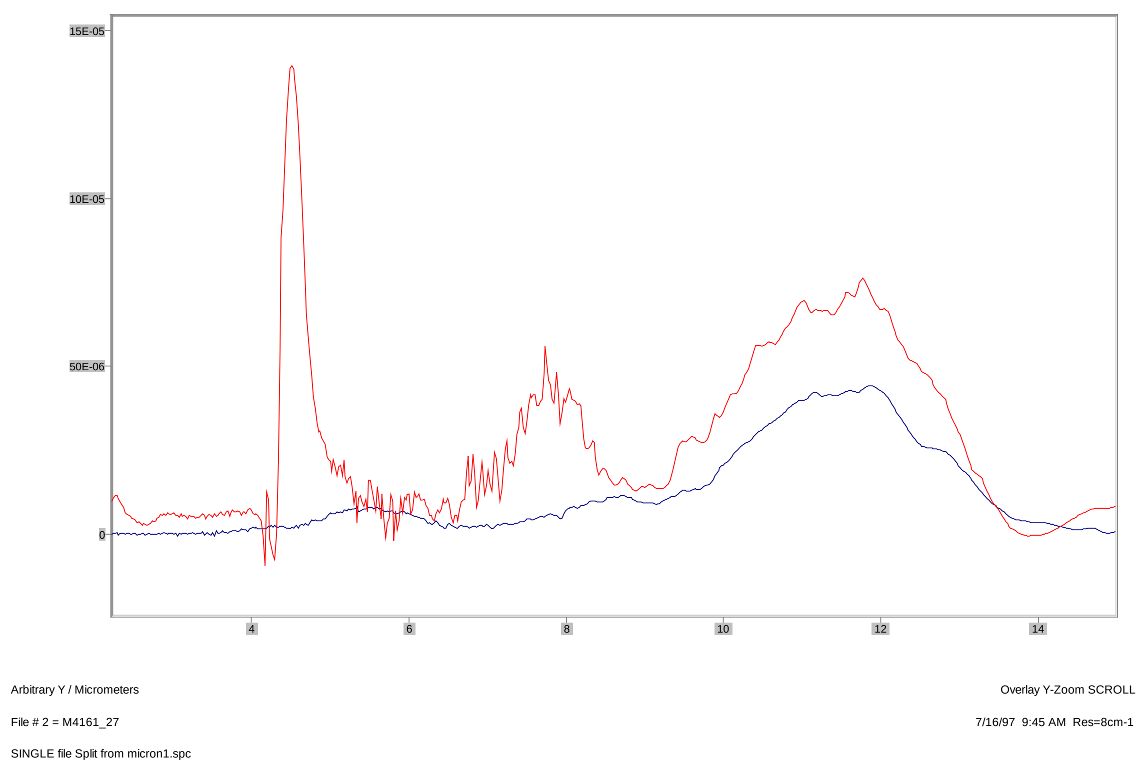


Arbitrary Y / Micrometers
Overlay Y-Zoom SCROLL
File # 2 = HS23_15
7/2/97 12:16 PM Res=8cm-1
SINGLE file Split from micron.spc

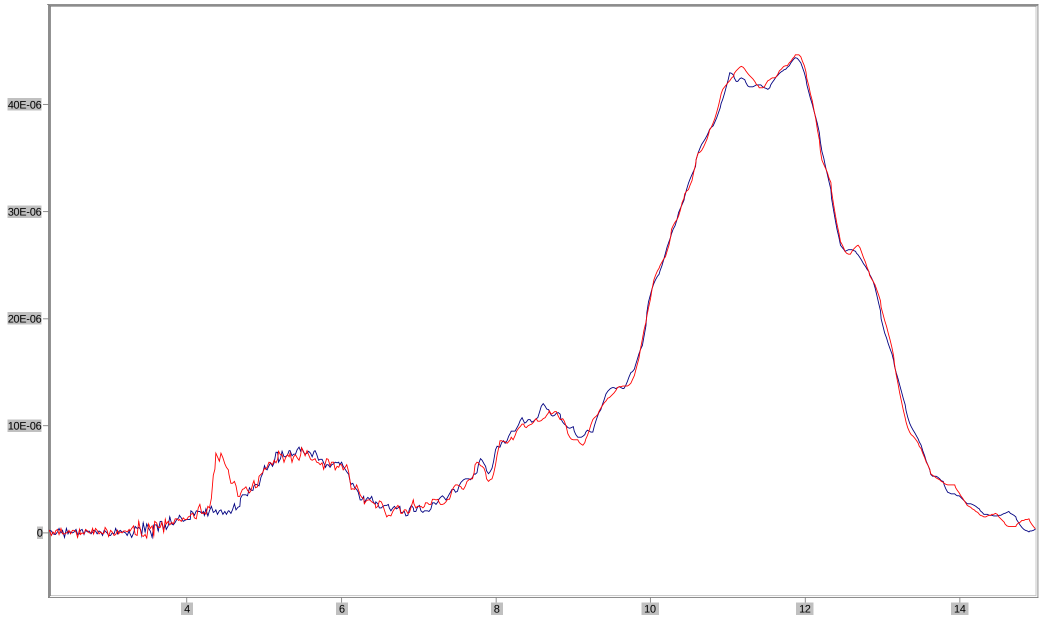
Graph III-24: Hy-Skor 700X Open Burn IR Spectra



Graph III-25: M14 Open Burn IR Spectra



Graph III-26: M14 Open Burn IR Spectra



Arbitrary Y / Micrometers

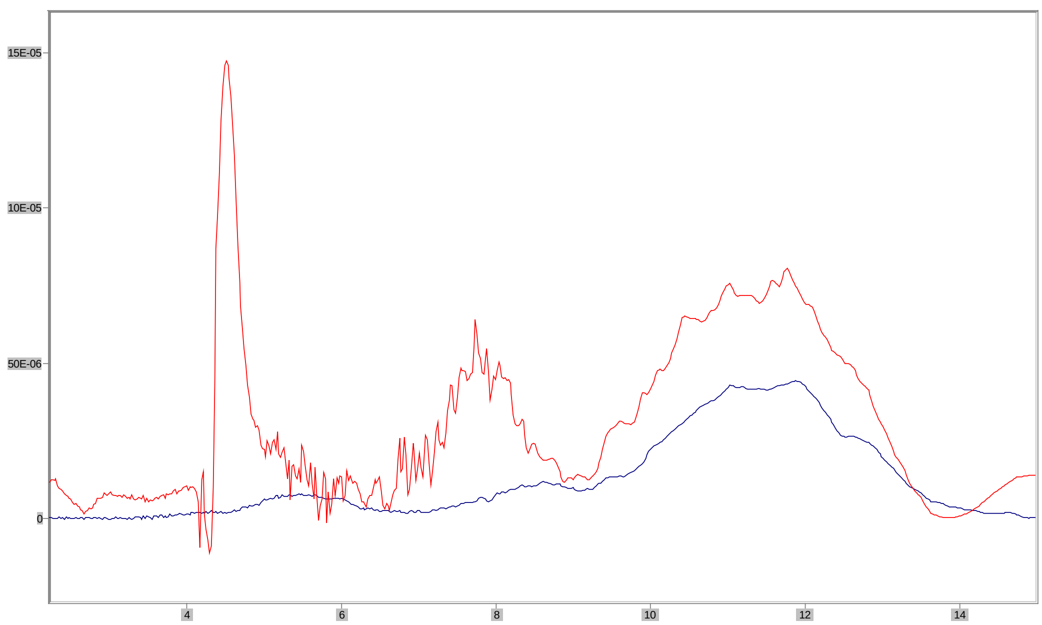
Overlay Y-Zoom SCROLL

File # 2 = M4162_17

7/16/97 10:01 AM Res=8cm-1

SINGLE file Split from micron.spc

Graph III-27: M14 Open Burn IR Spectra



Arbitrary Y / Micrometers

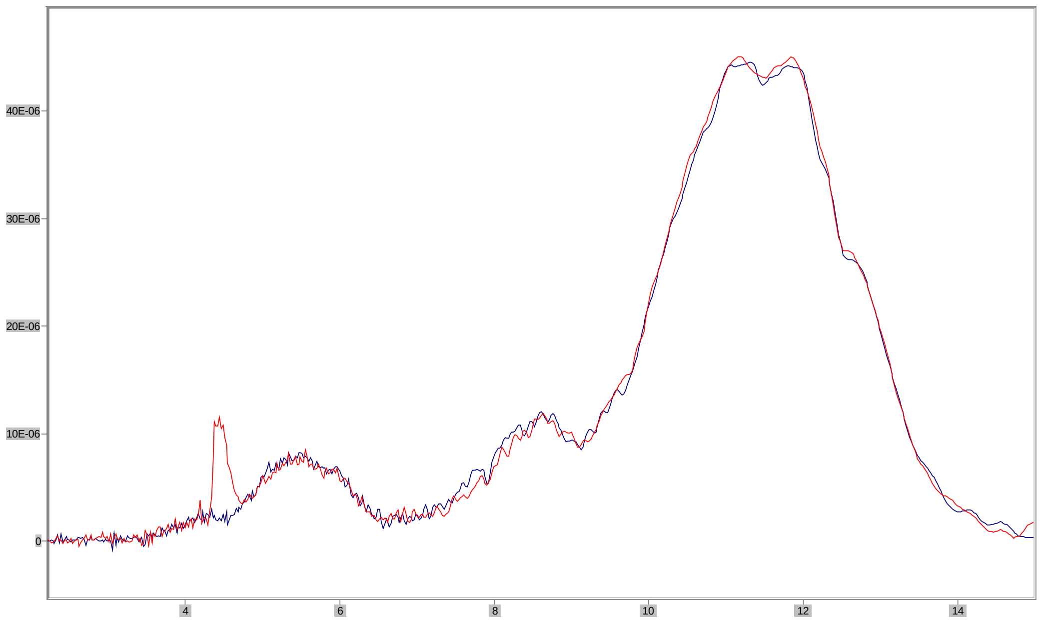
Overlay Y-Zoom SCROLL

File # 2 = M4162_41

7/16/97 10:01 AM Res=8cm-1

SINGLE file Split from micron.spc

Graph III-28: M14 Open Burn IR Spectra

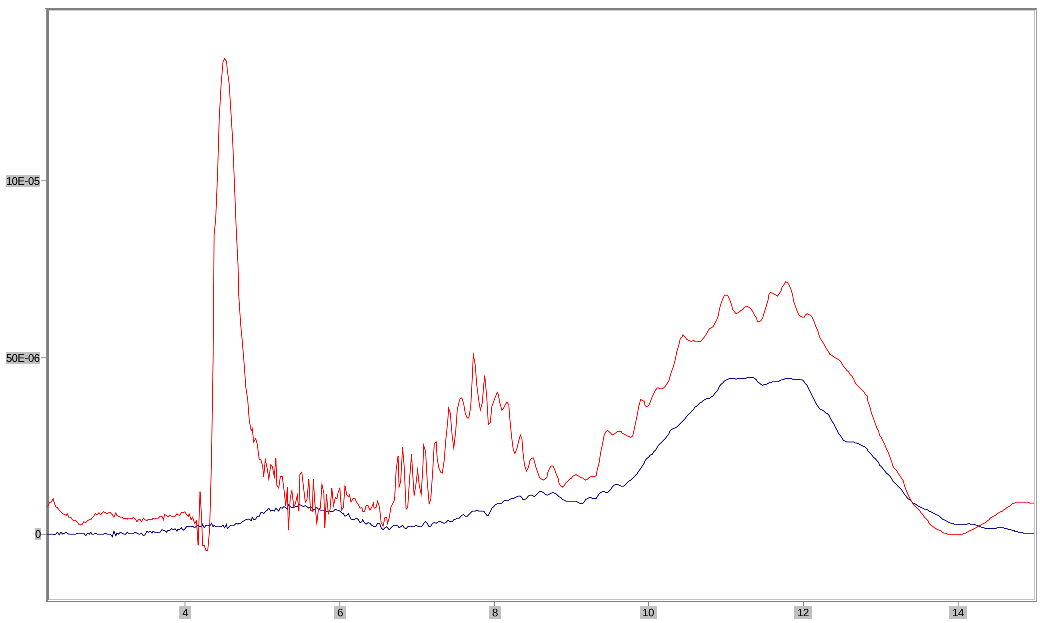


Arbitrary Y / Micrometers — Overlay Y-Zoom SCROLL

File # 2 = M4163_27 — 7/16/97 10:10 AM Res=8cm-1

SINGLE file Split from micron.spc

Graph III-29: M14 Open Burn IR Spectra

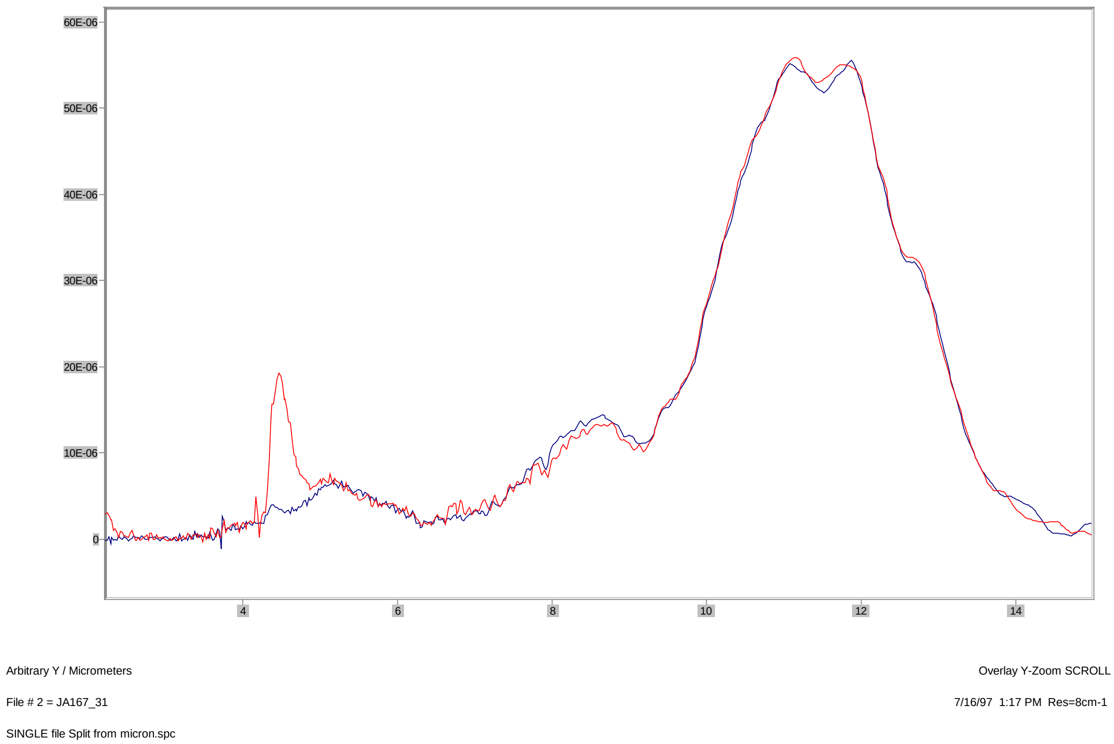


Arbitrary Y / Micrometers — Overlay Y-Zoom SCROLL

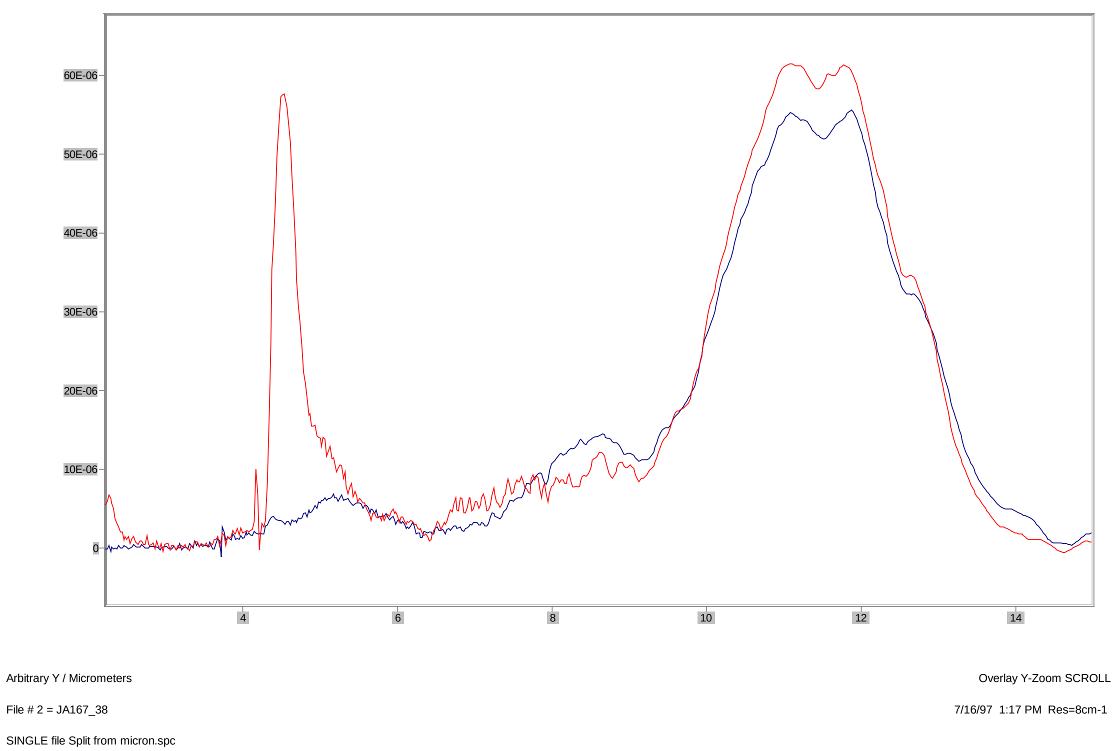
File # 2 = M4163_45 — 7/16/97 10:10 AM Res=8cm-1

SINGLE file Split from micron.spc

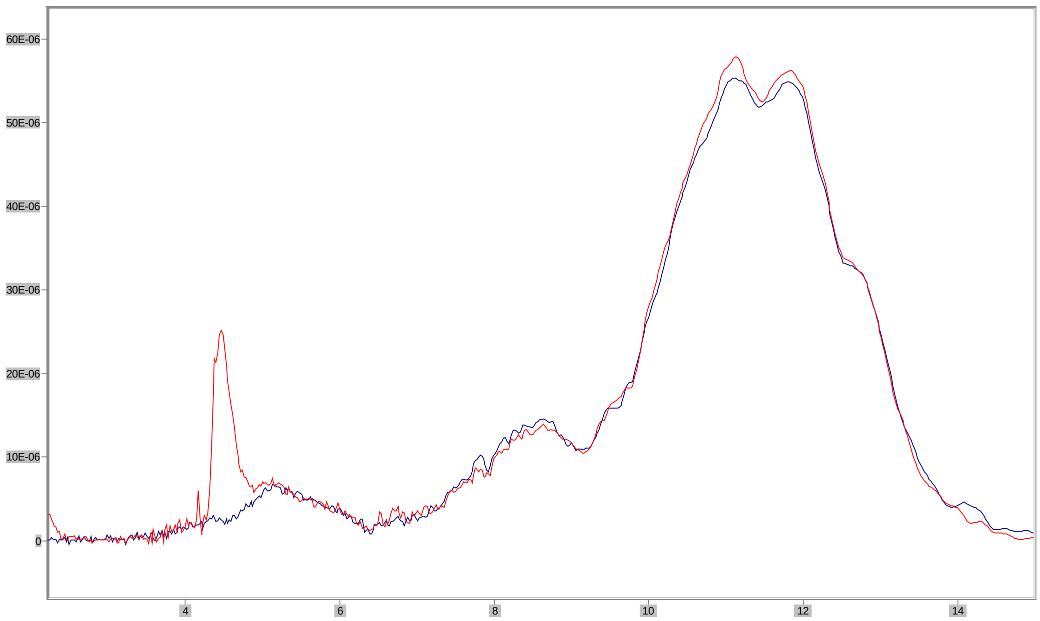
Graph III-30: M14 Open Burn IR Spectra



Graph III-31: JA-2 Open Burn IR Spectra



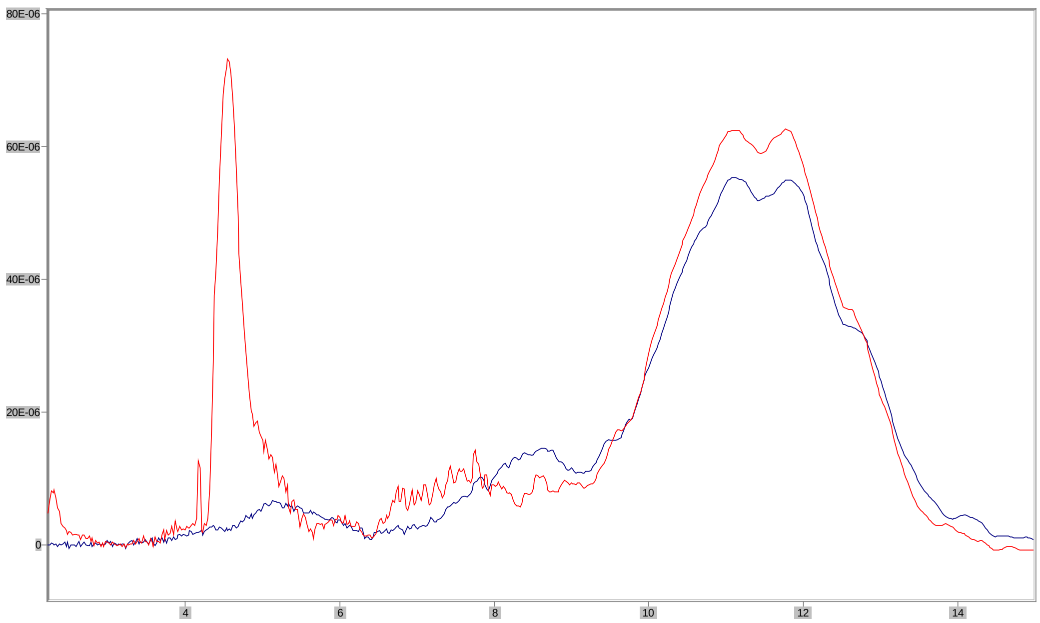
Graph III-32: JA-2 Open Burn IR Spectra



Arbitrary Y / Micrometers
File # 2 = JA168_34
SINGLE file Split from micron.spc

Overlay Y-Zoom SCROLL
7/16/97 1:28 PM Res=8cm-1

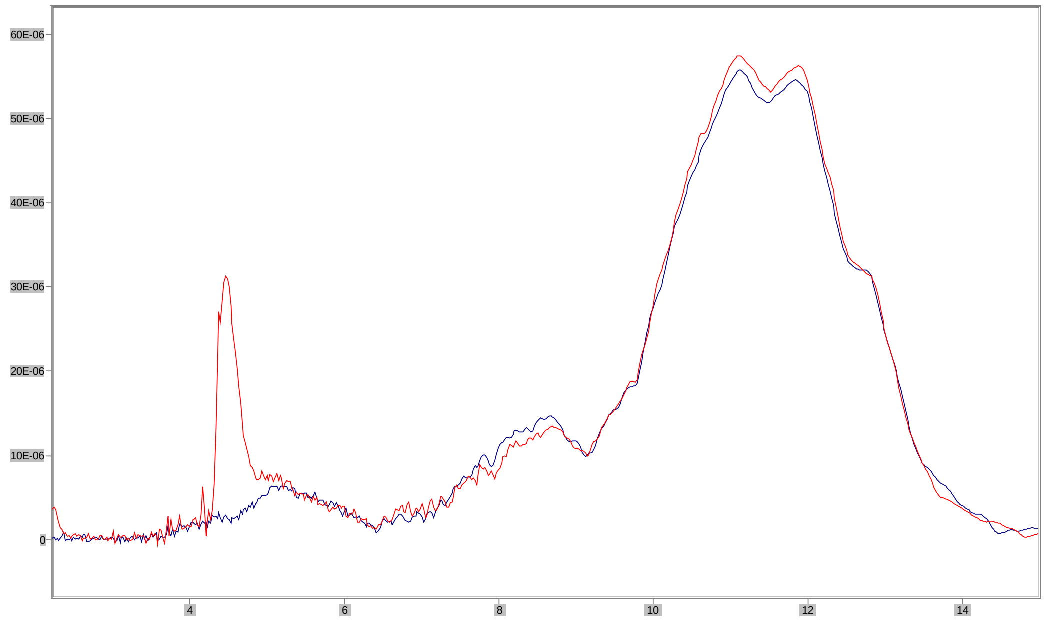
Graph III-33: JA-2 Open Burn IR Spectra



Arbitrary Y / Micrometers
File # 2 = JA168_49
SINGLE file Split from micron.spc

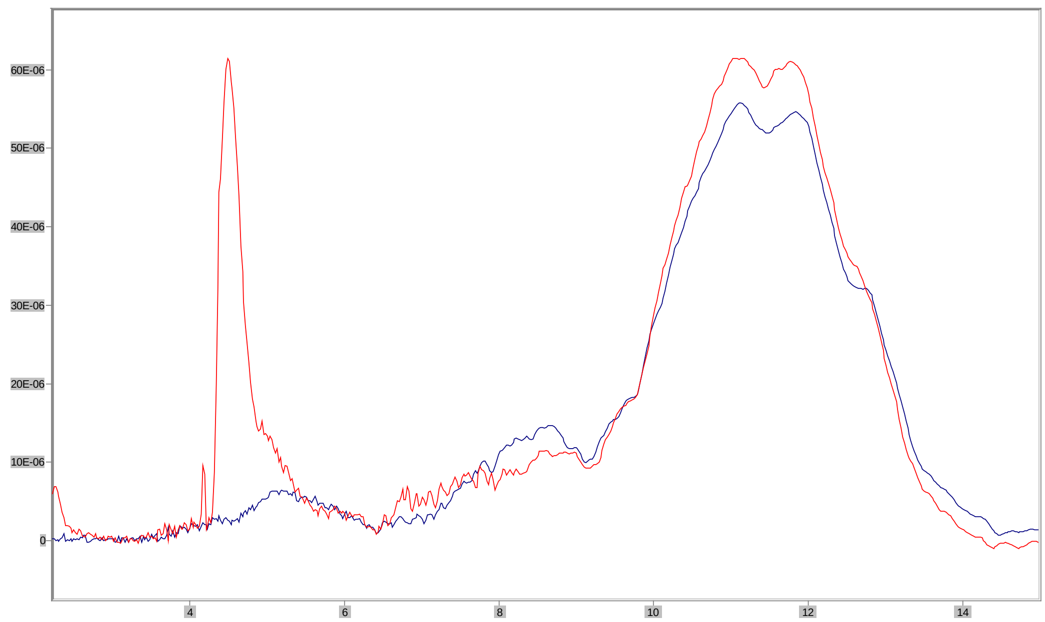
Overlay Y-Zoom SCROLL
7/16/97 1:28 PM Res=8cm-1

Graph III-34: JA-2 Open Burn IR Spectra



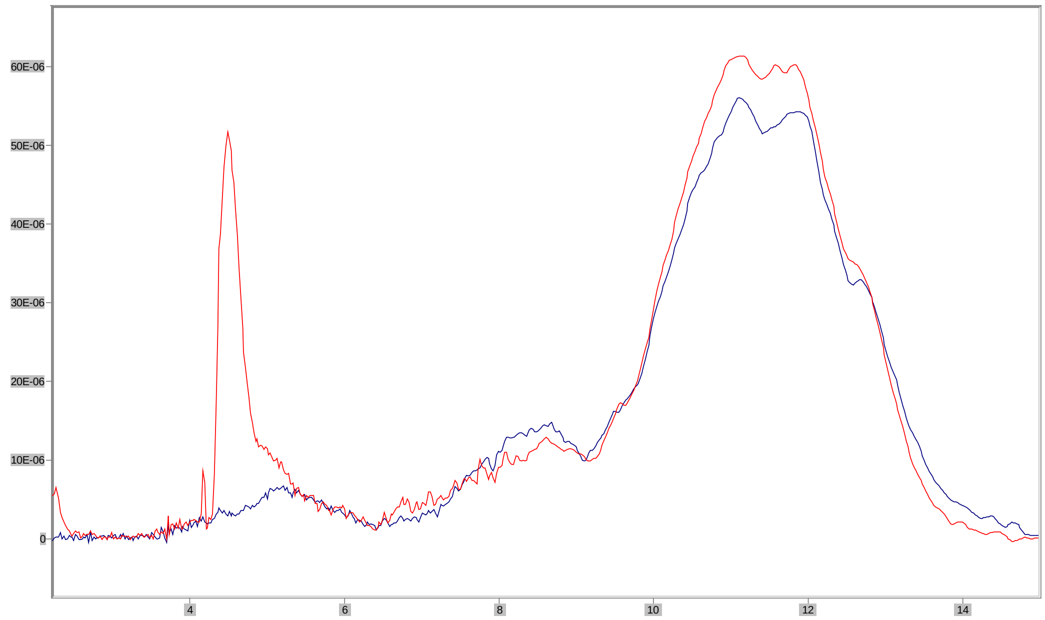
Arbitrary Y / Micrometers
Overlay Y-Zoom SCROLL
File # 2 = JA169_32
7/16/97 1:37 PM Res=8cm-1
SINGLE file Split from micron.spc

Graph III-35: JA-2 Open Burn IR Spectra



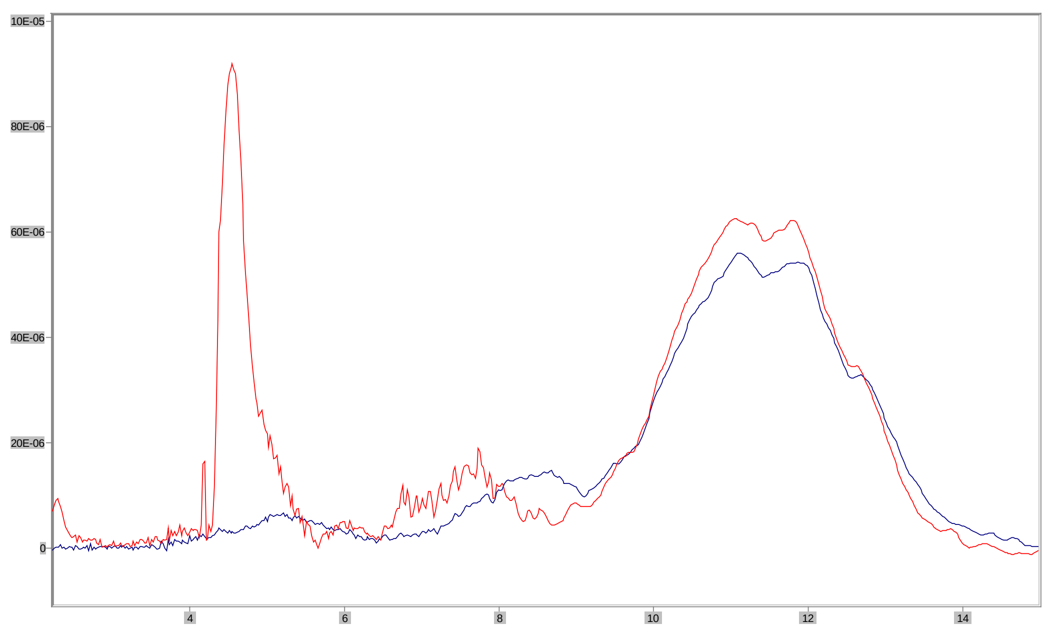
Arbitrary Y / Micrometers
Overlay Y-Zoom SCROLL
File # 2 = JA169_40
7/16/97 1:37 PM Res=8cm-1
SINGLE file Split from micron.spc

Graph III-36: JA-2 Open Burn IR Spectra



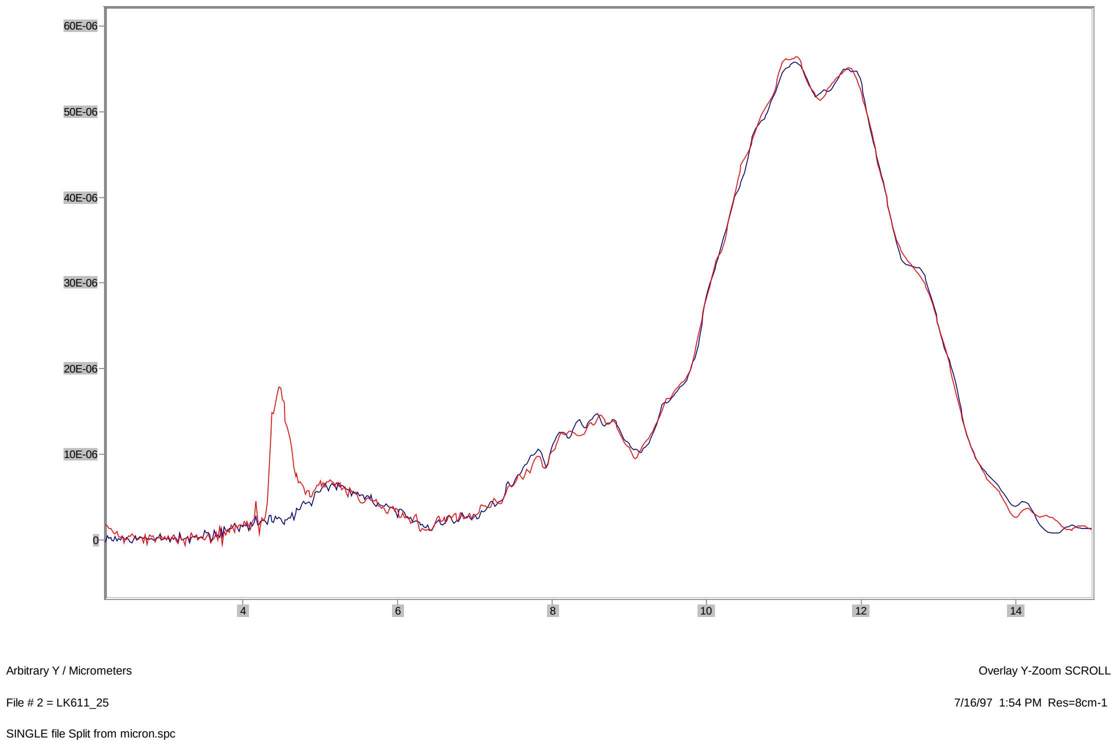
Arbitrary Y / Micrometers
Overlay Y-Zoom SCROLL
File # 2 = LK610_25
7/16/97 1:46 PM Res=8cm-1
SINGLE file Split from micron.spc

Graph III-37: LKL Open Burn IR Spectra

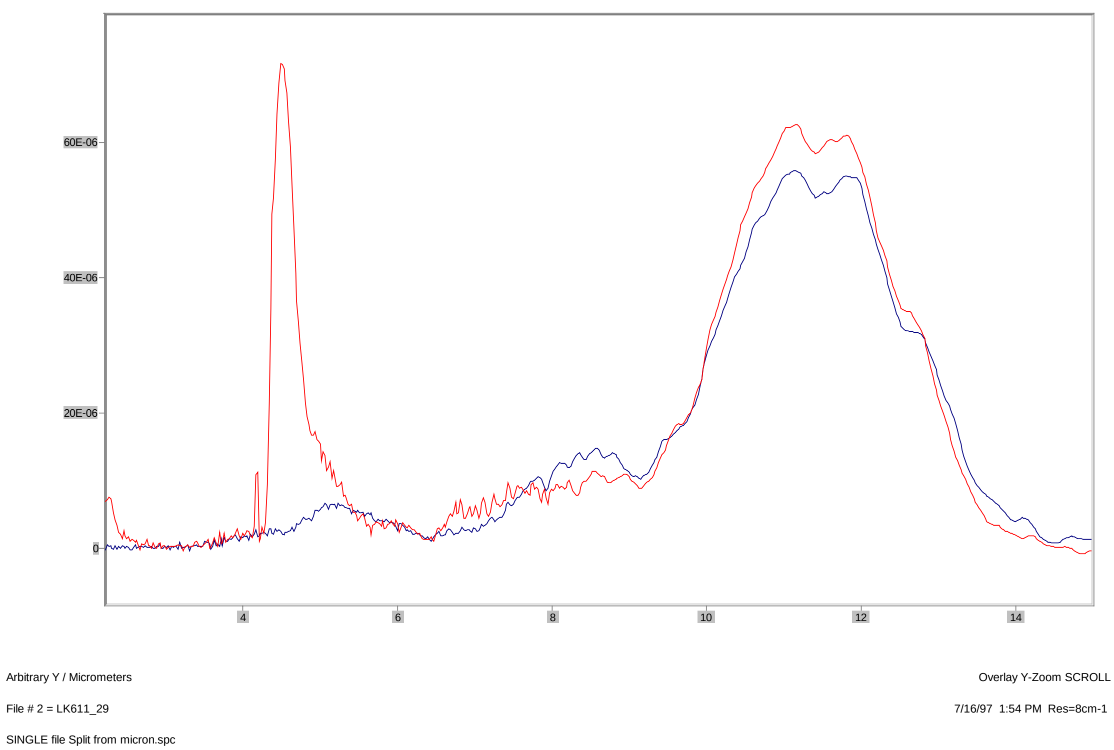


Arbitrary Y / Micrometers
Overlay Y-Zoom SCROLL
File # 2 = LK610_33
7/16/97 1:46 PM Res=8cm-1
SINGLE file Split from micron.spc

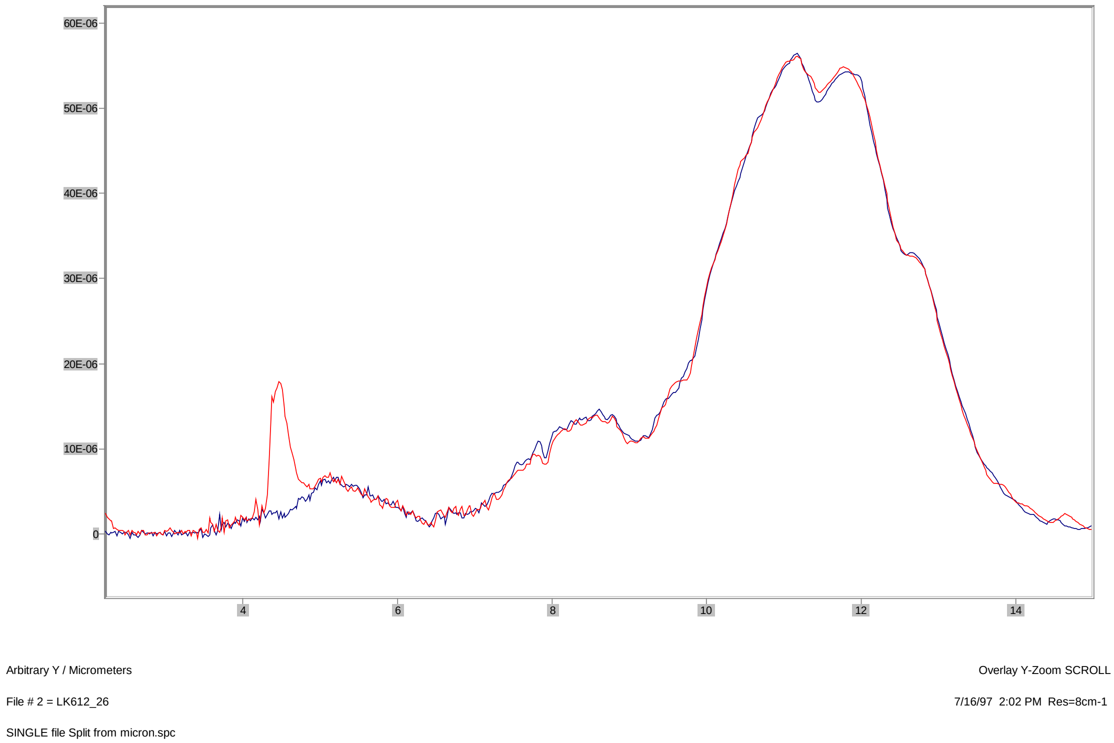
Graph III-38: LKL Open Burn IR Spectra



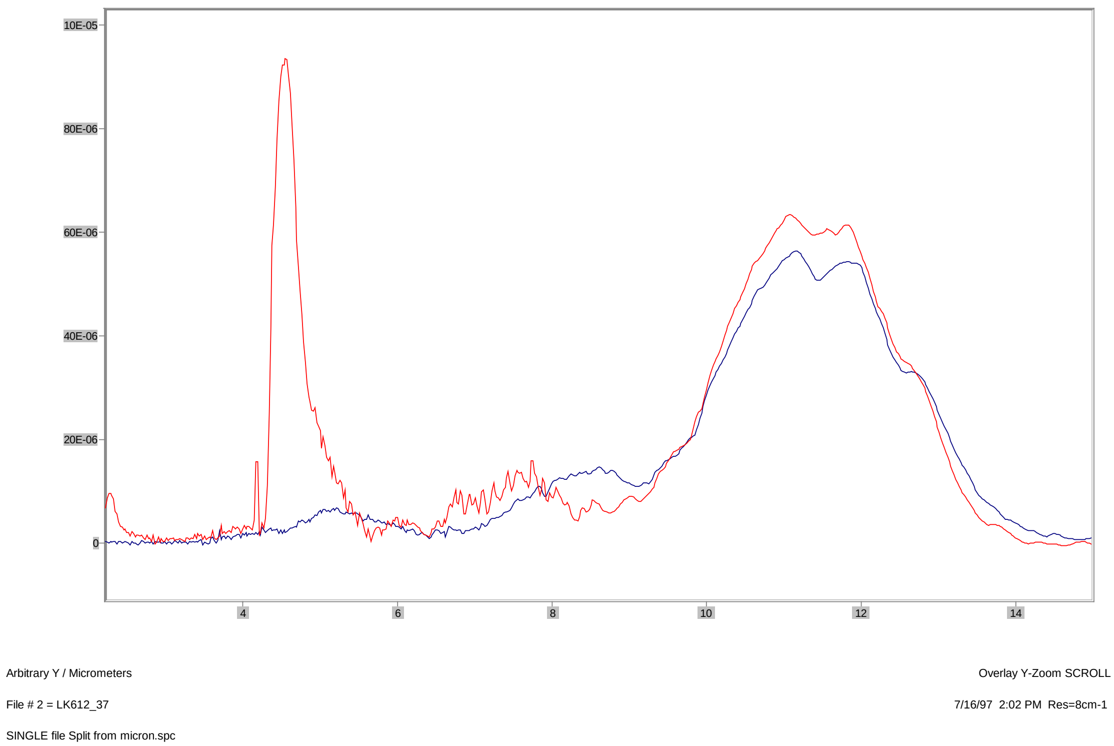
Graph III-39: LKL Open Burn IR Spectra



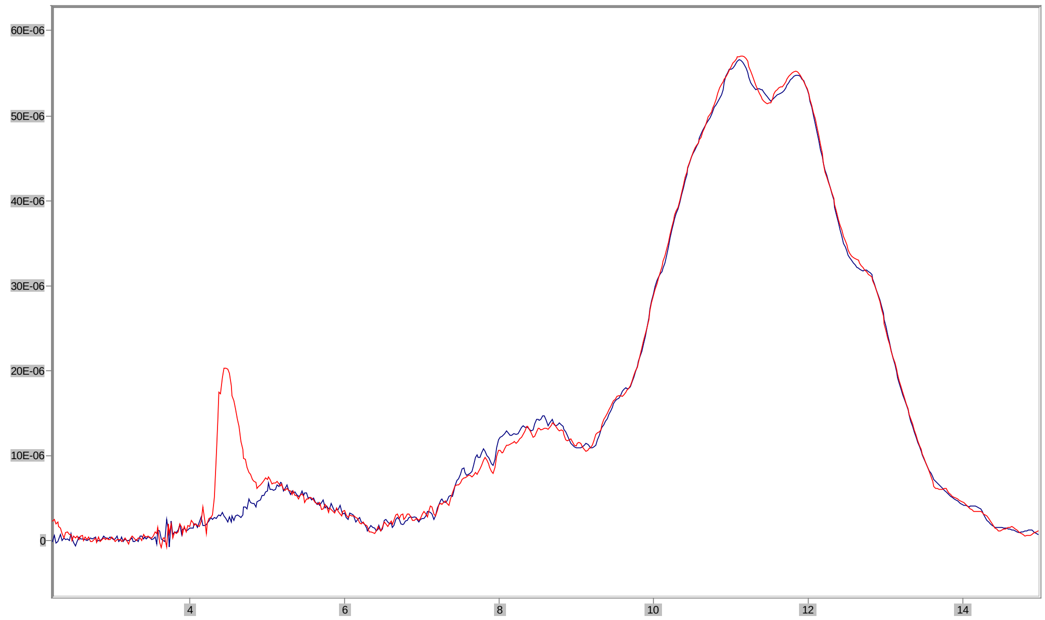
Graph III-40: LKL Open Burn IR Spectra



Graph III-41: LKL Open Burn IR Spectra



Graph III-42: LKL Open Burn IR Spectra



Arbitrary Y / Micrometers

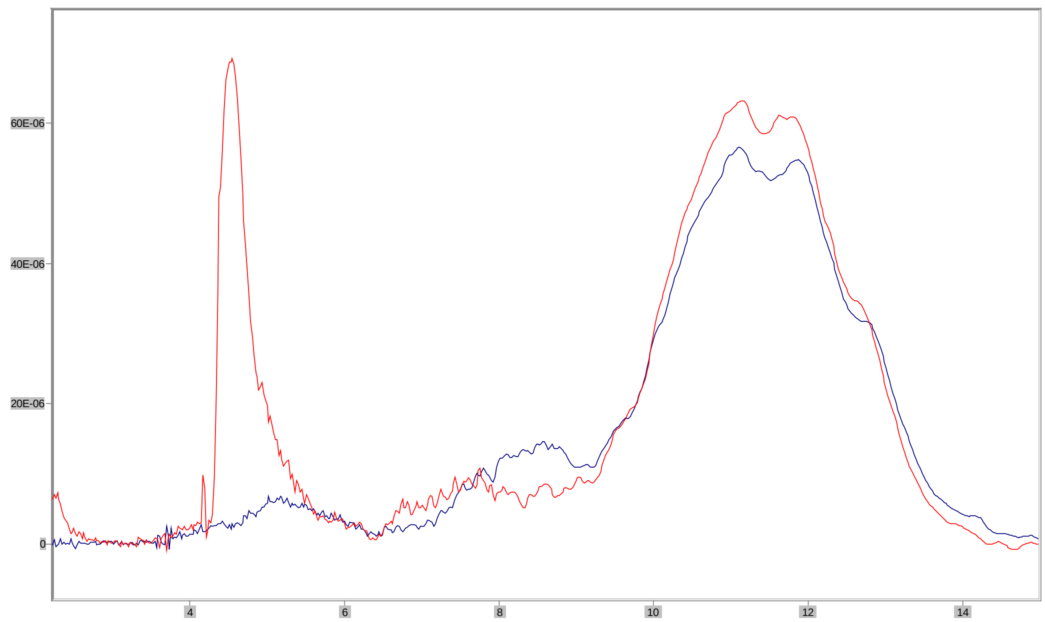
Overlay Y-Zoom SCROLL

File # 2 = X1613_47

7/16/97 2:14 PM Res=8cm-1

SINGLE file Split from micron.spc

Graph III-43: PBX-9501 Open Burn IR Spectra



Arbitrary Y / Micrometers

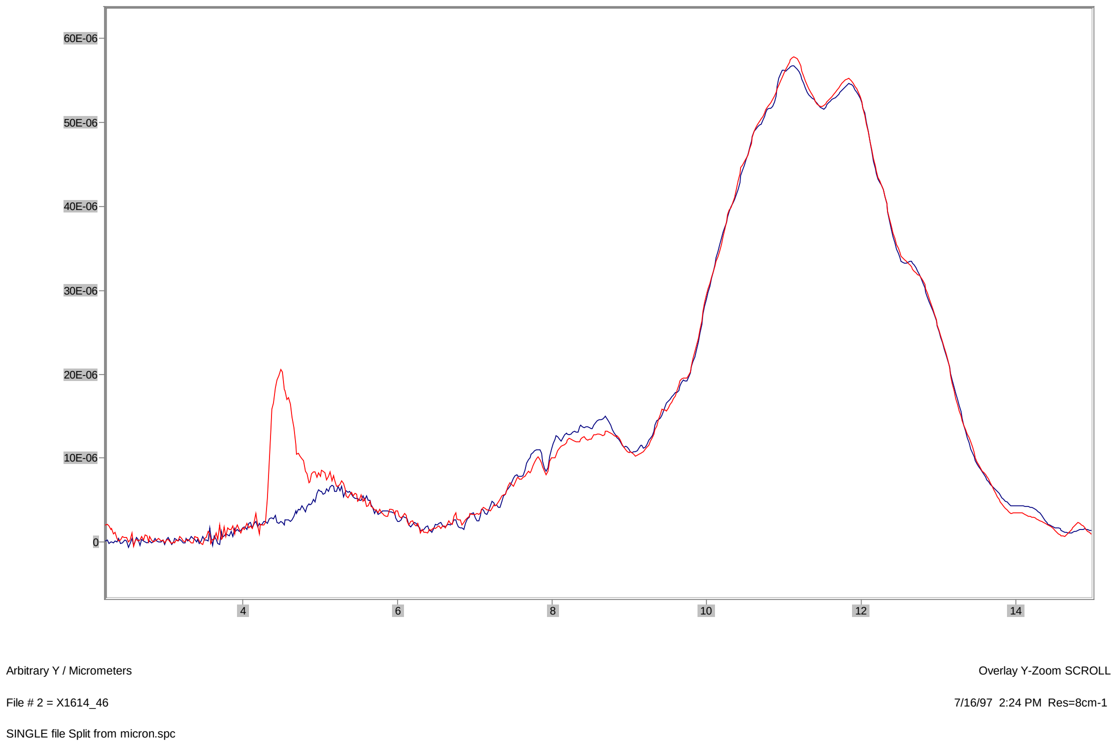
Overlay Y-Zoom SCROLL

File # 2 = X1613_72

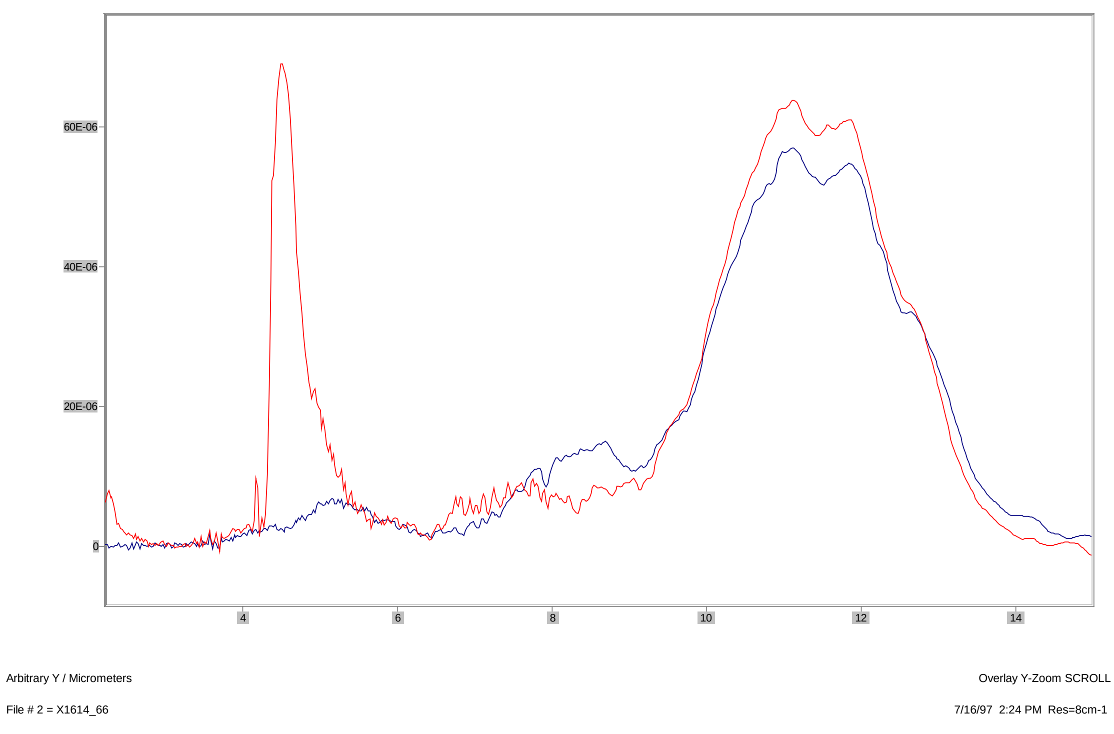
7/16/97 2:14 PM Res=8cm-1

SINGLE file Split from micron.spc

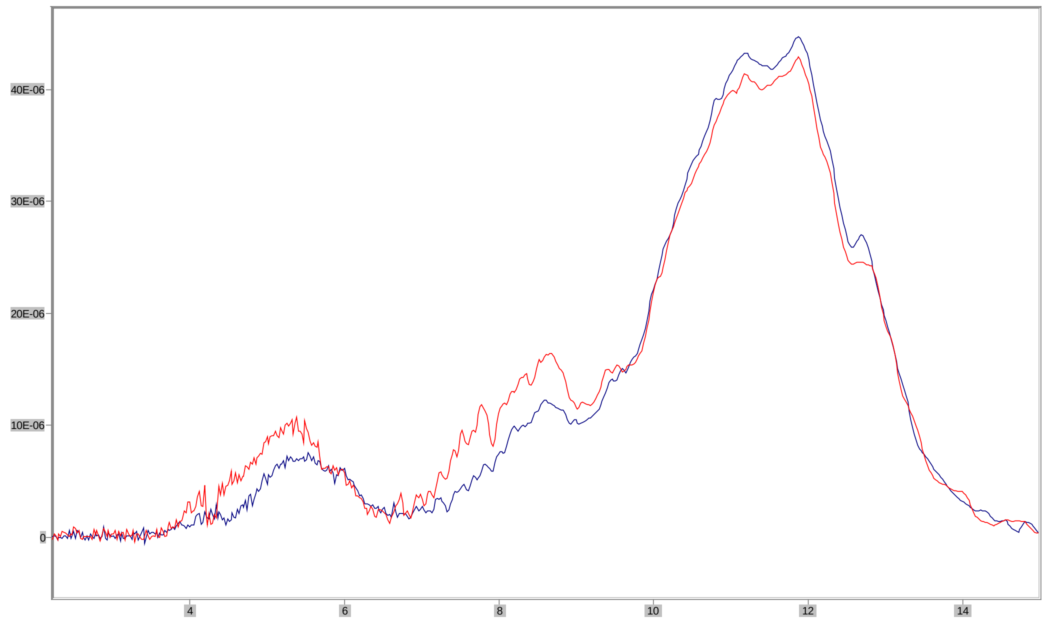
Graph III-44: PBX-9501 Open Burn IR Spectra



Graph III-45: PBX-9501 Open Burn IR Spectra



Graph III-46: PBX-9501 Open Burn IR Spectra



Arbitrary Y / Micrometers

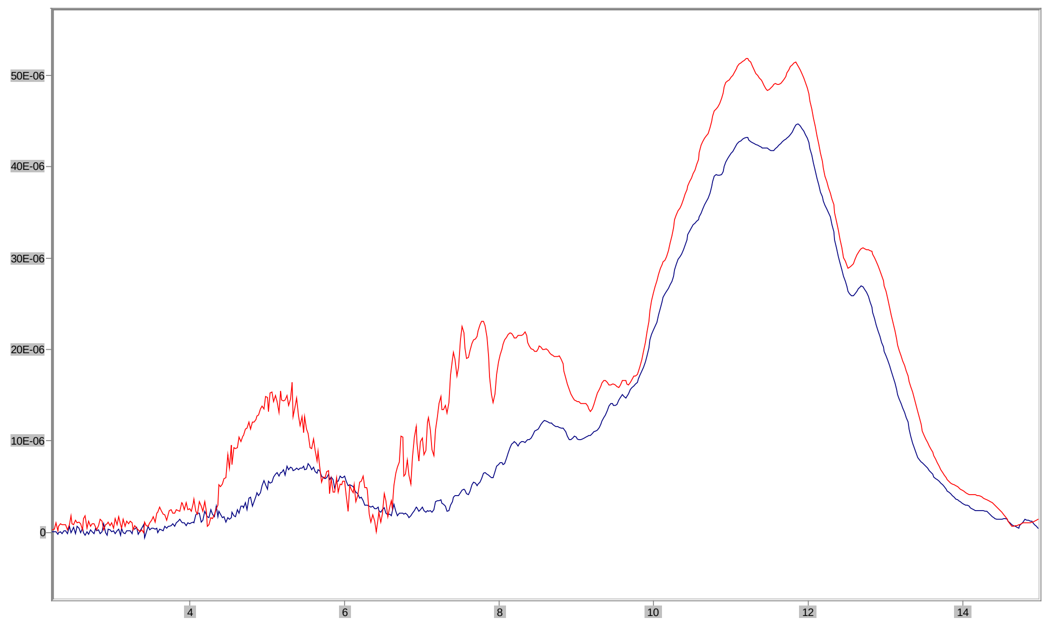
Overlay Y-Zoom SCROLL

File # 2 = M538_50

7/3/97 8:44 AM Res=8cm-1

SINGLE file Split from micron.spc

Graph III-47: MK-25 Open Burn IR Spectra



Arbitrary Y / Micrometers

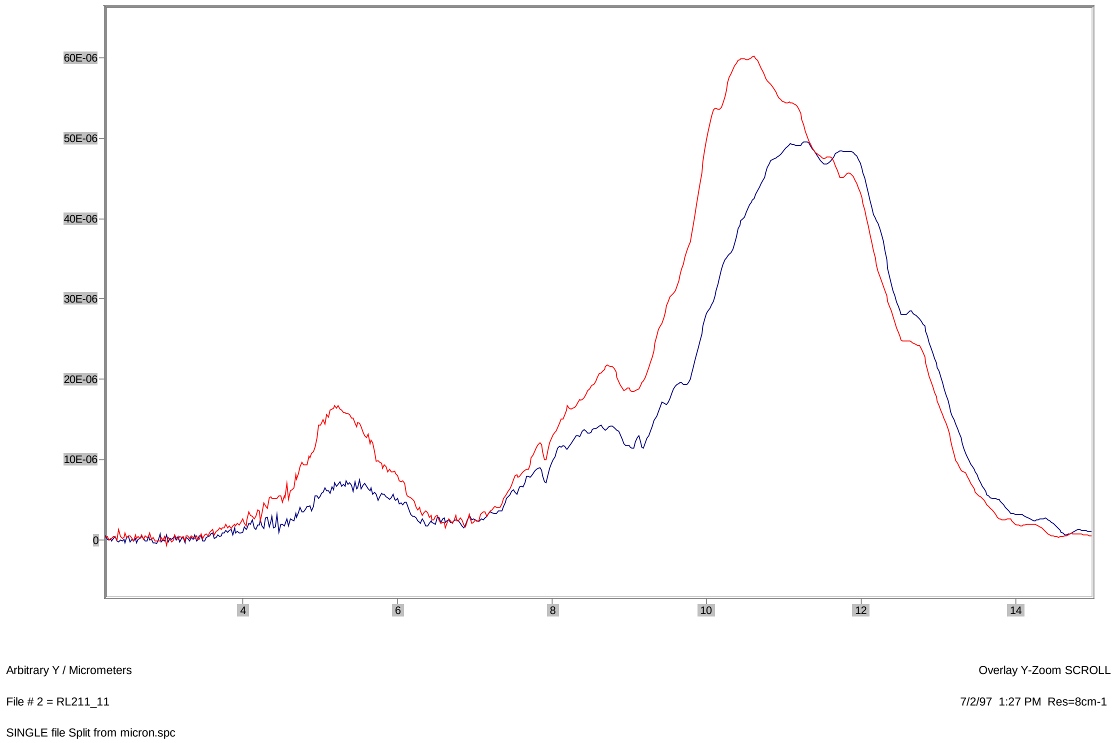
Overlay Y-Zoom SCROLL

File # 2 = M538_100

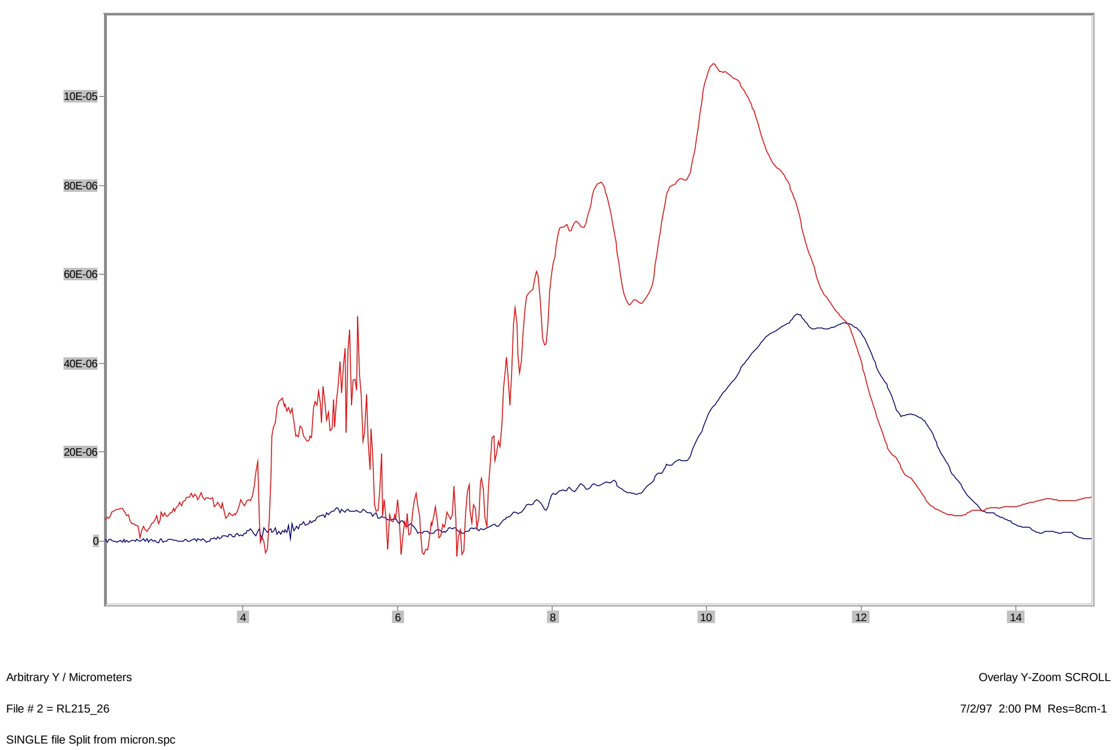
7/3/97 8:44 AM Res=8cm-1

SINGLE file Split from micron.spc

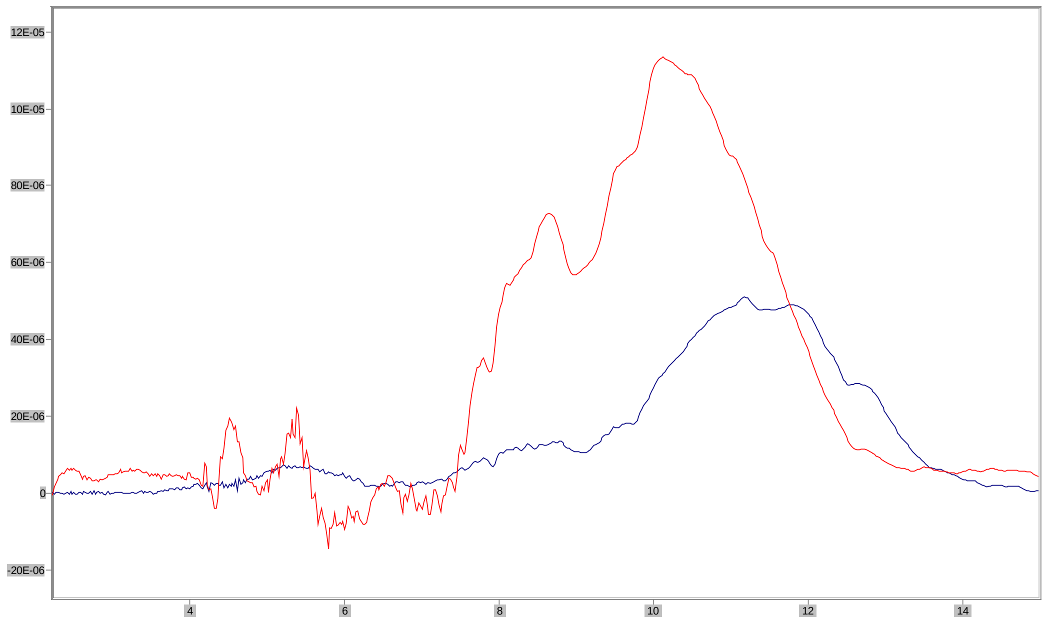
Graph III-48: MK-25 Open Burn IR Spectra



Graph III-49: Red Lead Open Burn IR Spectra



Graph III-50: Red Lead Open Burn IR Spectra



Arbitrary Y / Micrometers

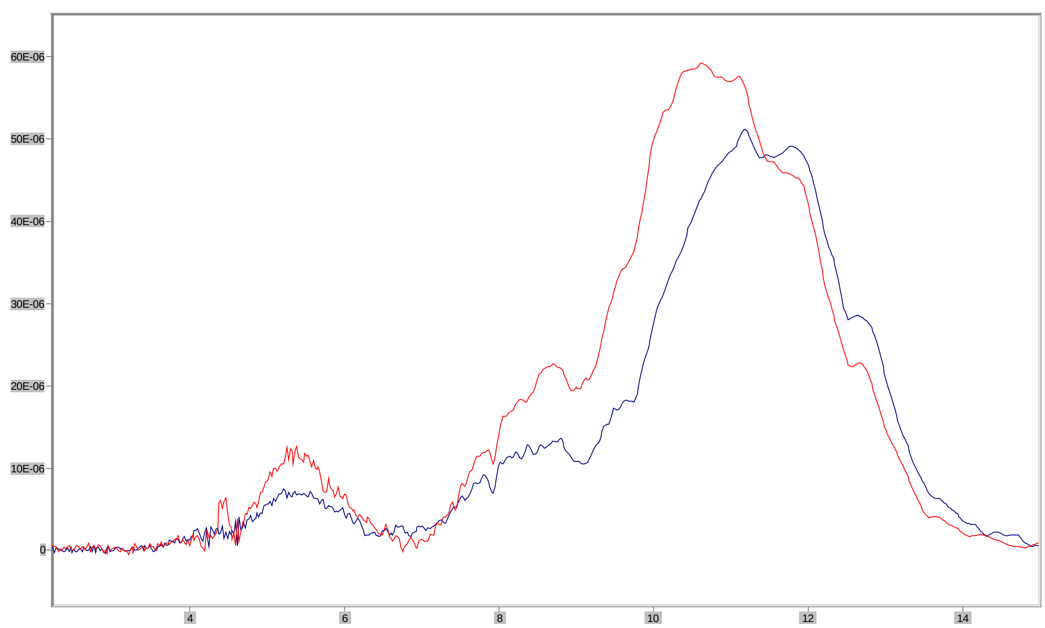
Overlay Y-Zoom SCROLL

File # 2 = RL215_27

7/2/97 2:00 PM Res=8cm-1

SINGLE file Split from micron.spc

Graph III-51: Red Lead Open Burn IR Spectra



Arbitrary Y / Micrometers

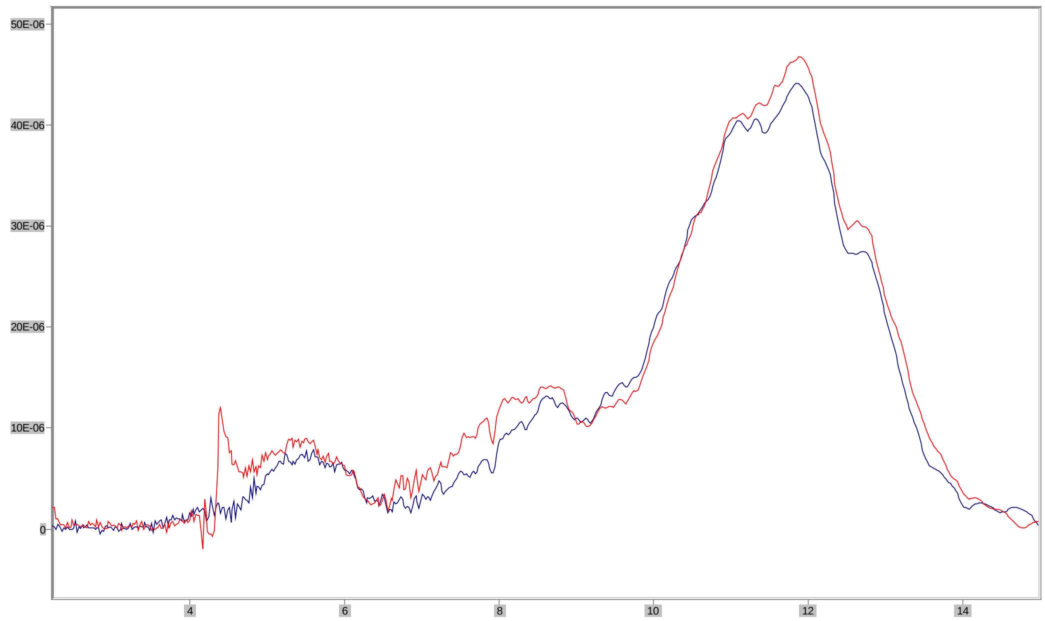
Overlay Y-Zoom SCROLL

File # 2 = RL215_28

7/2/97 2:00 PM Res=8cm-1

SINGLE file Split from micron.spc

Graph III-52: Red Lead Open Burn IR Spectra



Arbitrary Y / Micrometers

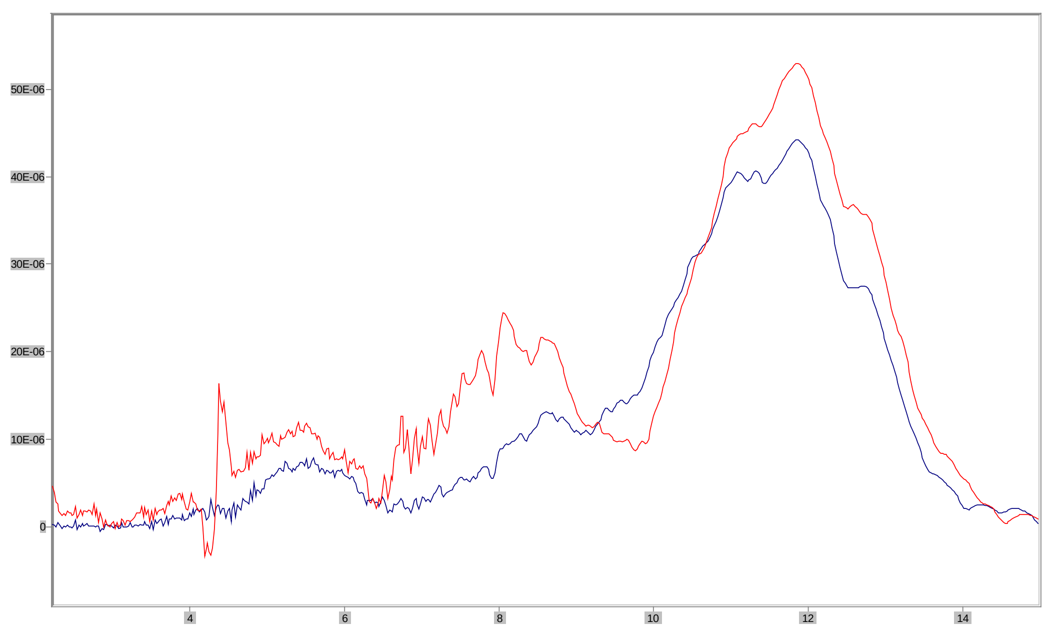
Overlay Y-Zoom SCROLL

File # 2 = GS34_28

7/3/97 8:00 AM Res=8cm-1

SINGLE file Split from micron.spc

Graph III-53: Green Smoke Open Burn IR Spectra



Arbitrary Y / Micrometers

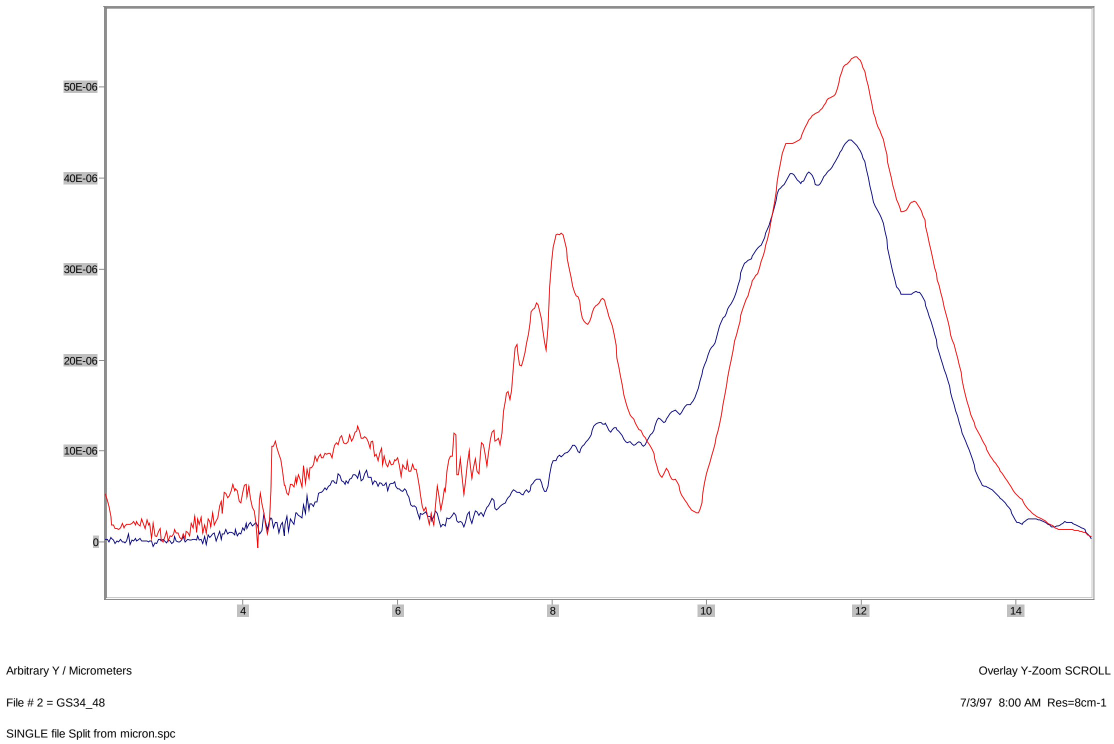
Overlay Y-Zoom SCROLL

File # 2 = GS34_38

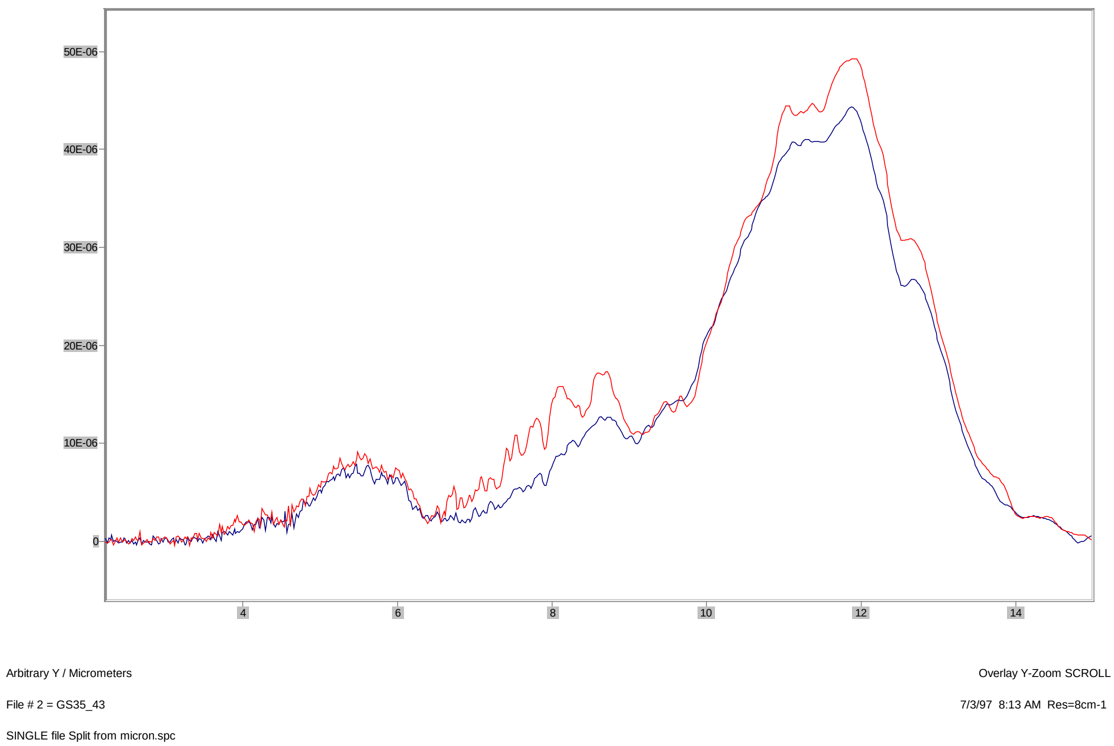
7/3/97 8:00 AM Res=8cm-1

SINGLE file Split from micron.spc

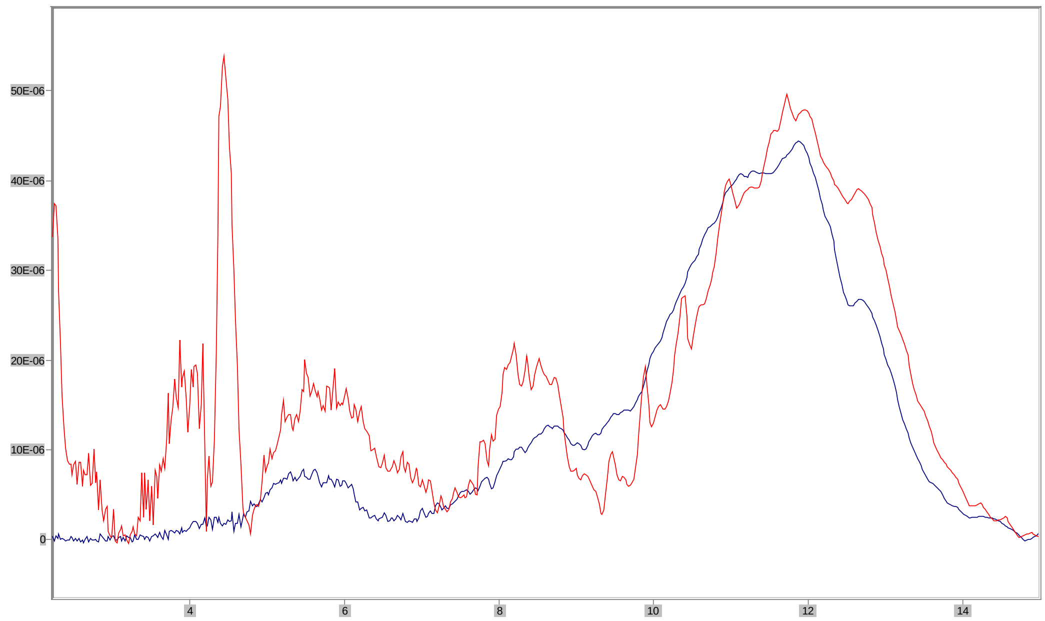
Graph III-54: Green Smoke Open Burn IR Spectra



Graph III-55: Green Smoke Open Burn IR Spectra

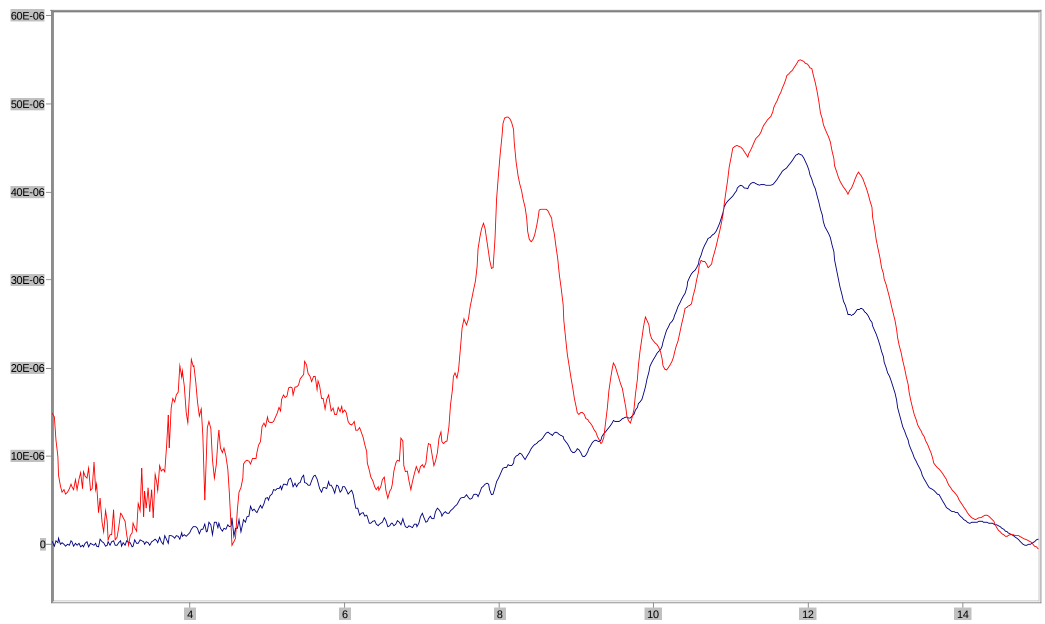


Graph III-56: Green Smoke Open Burn IR Spectra



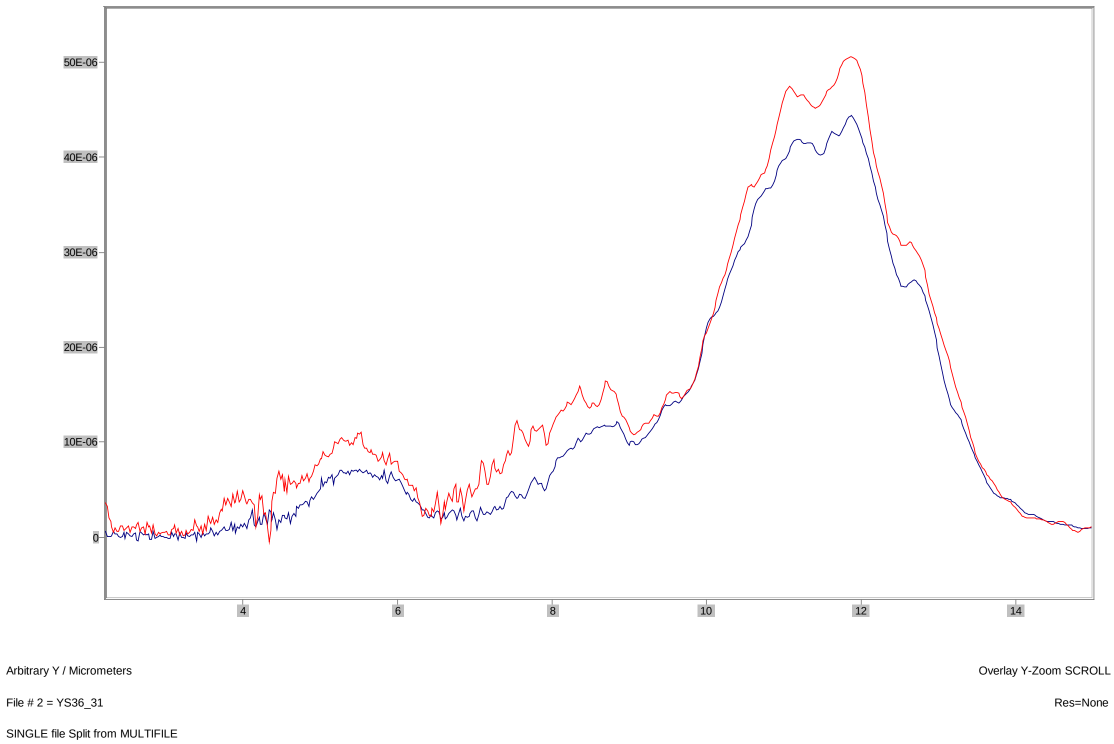
Arbitrary Y / Micrometers
Overlay Y-Zoom SCROLL
File # 2 = GS35_45
7/3/97 8:13 AM Res=8cm-1
SINGLE file Split from micron.spc

Graph III-57: Green Smoke Open Burn IR Spectra

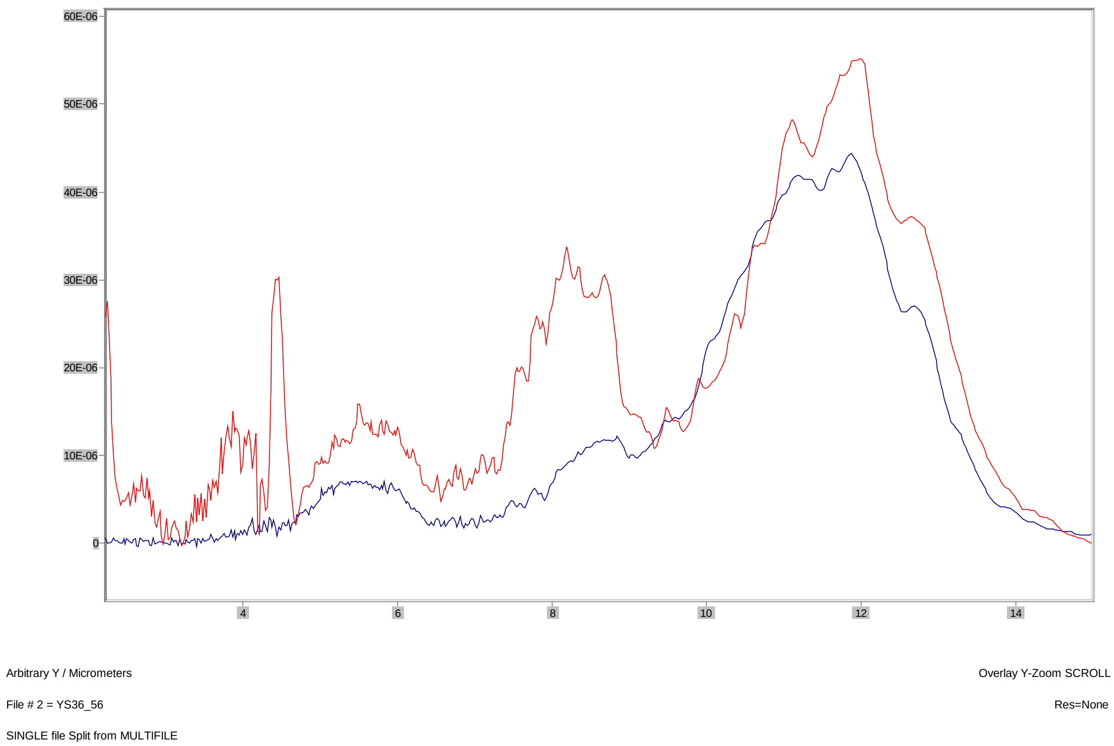


Arbitrary Y / Micrometers
Overlay Y-Zoom SCROLL
File # 2 = GS35_60
7/3/97 8:13 AM Res=8cm-1
SINGLE file Split from micron.spc

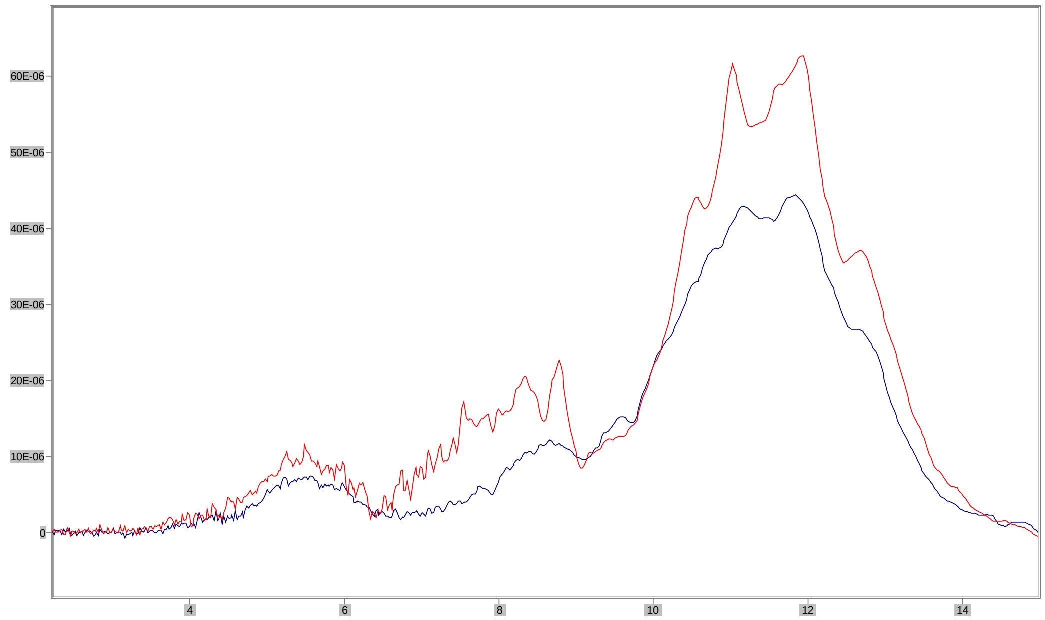
Graph III-58: Green Smoke Open Burn IR Spectra



Graph III-59: Yellow Smoke Open Burn IR Spectra



Graph III-60: Yellow Smoke Open Burn IR Spectra

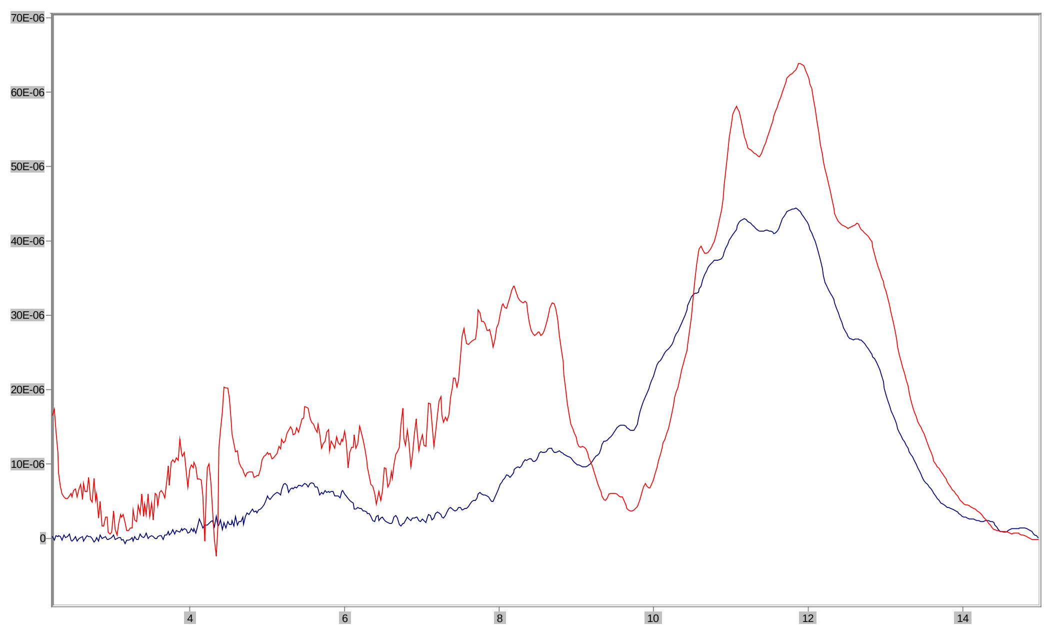


Arbitrary Y / Micrometers
Overlay Y-Zoom SCROLL

File # 2 = YS37_44
Res=None

SINGLE file Split from MULTIFILE

Graph III-61: Yellow Smoke Open Burn IR Spectra

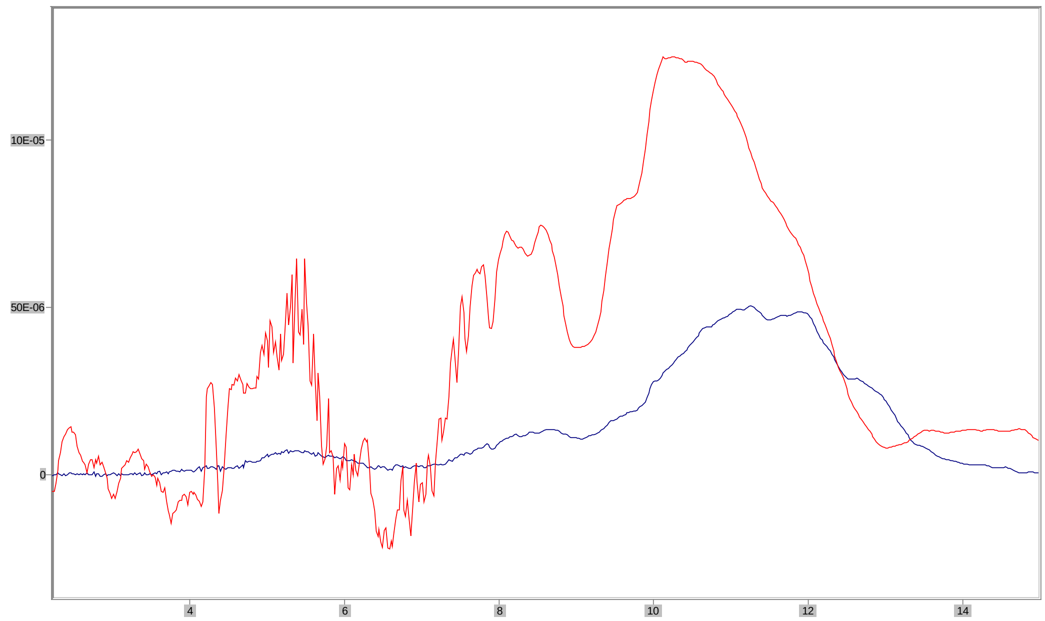


Arbitrary Y / Micrometers
Overlay Y-Zoom SCROLL

File # 2 = YS37_48
Res=None

SINGLE file Split from MULTIFILE

Graph III-62: Yellow Smoke Open Burn IR Spectra



Arbitrary Y / Micrometers

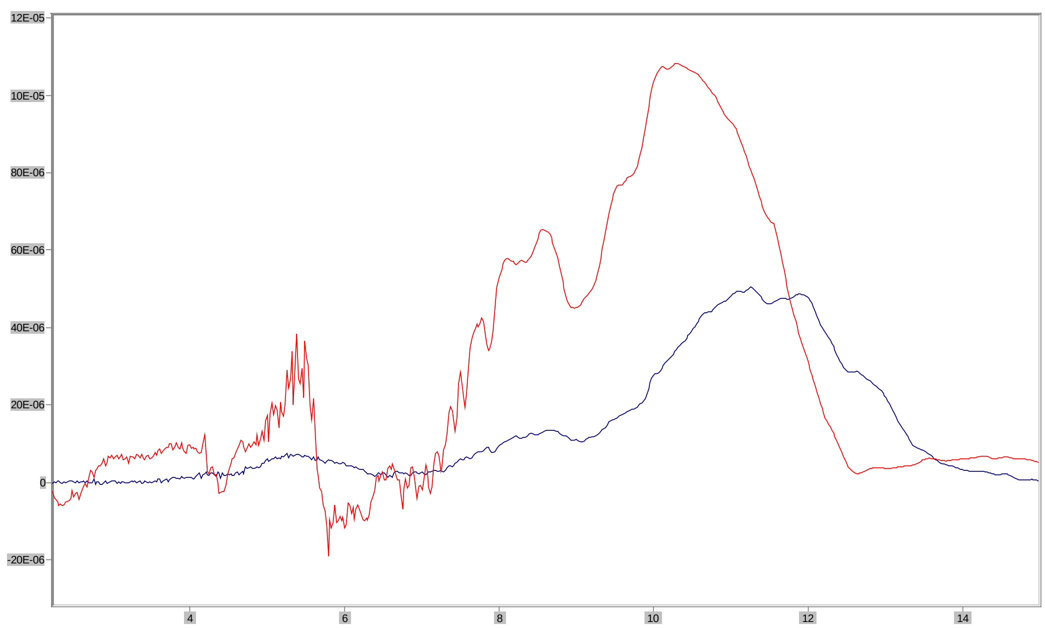
Overlay Y-Zoom SCROLL

File # 2 = M2213_19

7/2/97 1:44 PM Res=8cm-1

SINGLE file Split from micron1.spc

Graph III-63: M206 Open Burn IR Spectra



Arbitrary Y / Micrometers

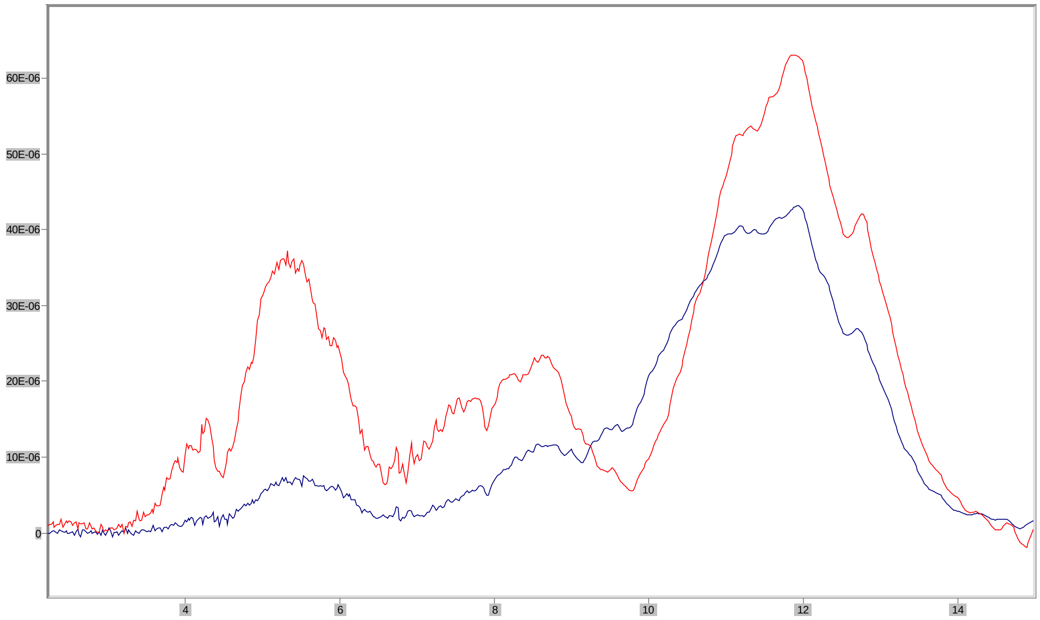
Overlay Y-Zoom SCROLL

File # 2 = M2213_20

7/2/97 1:44 PM Res=8cm-1

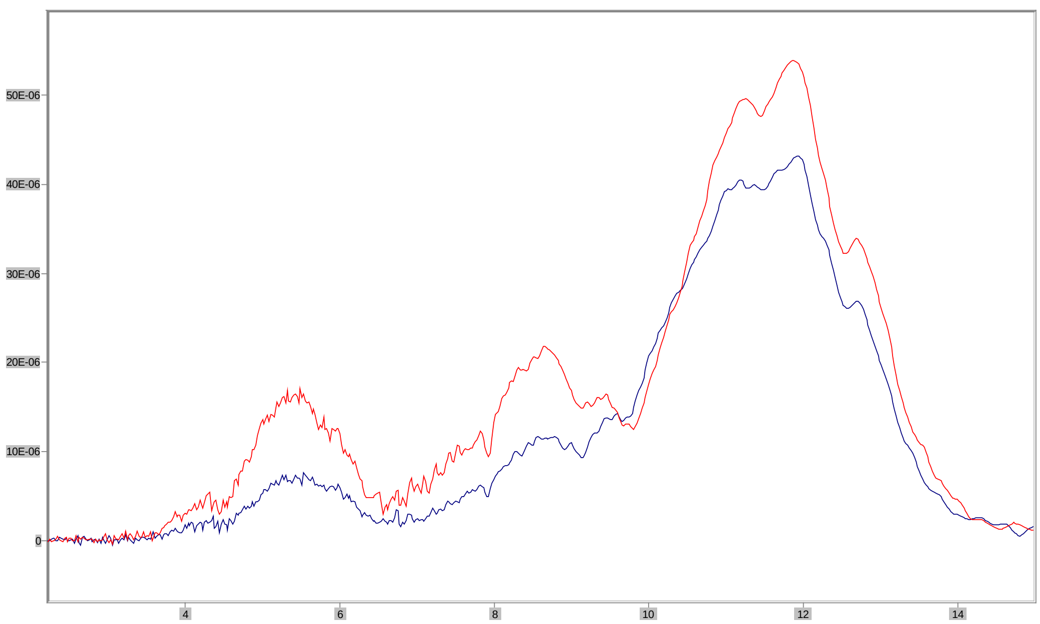
SINGLE file Split from micron1.spc

Graph III-64: M206 Open Burn IR Spectra



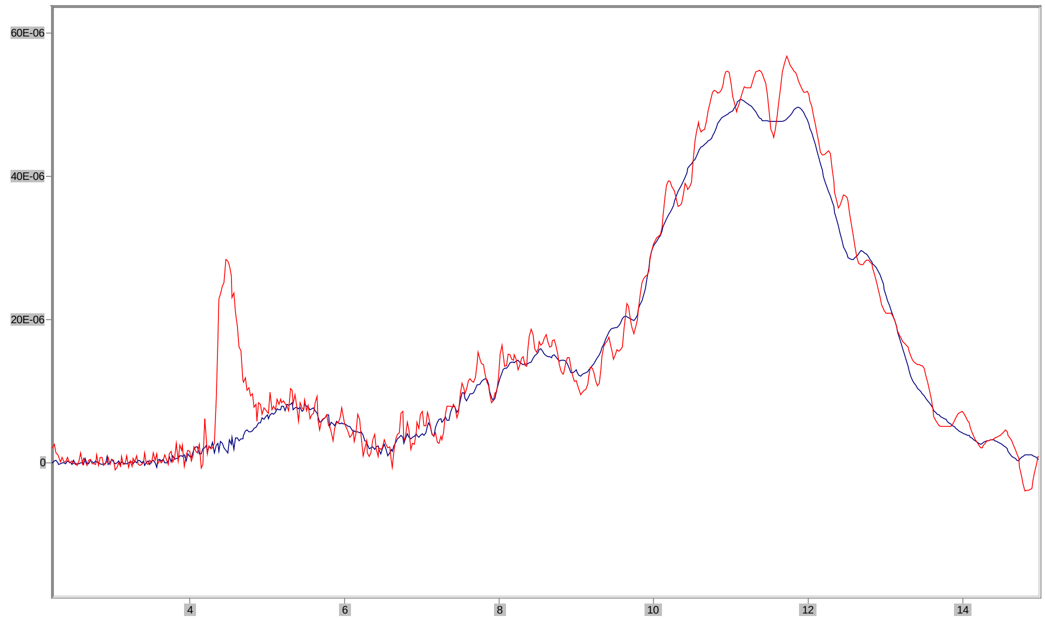
Arbitrary Y / Micrometers
Overlay Y-Zoom SCROLL
File # 2 = M222_75
7/2/97 12:02 PM Res=8cm-1
SINGLE file Split from micron.spc

Graph III-65: M206 Open Burn IR Spectra



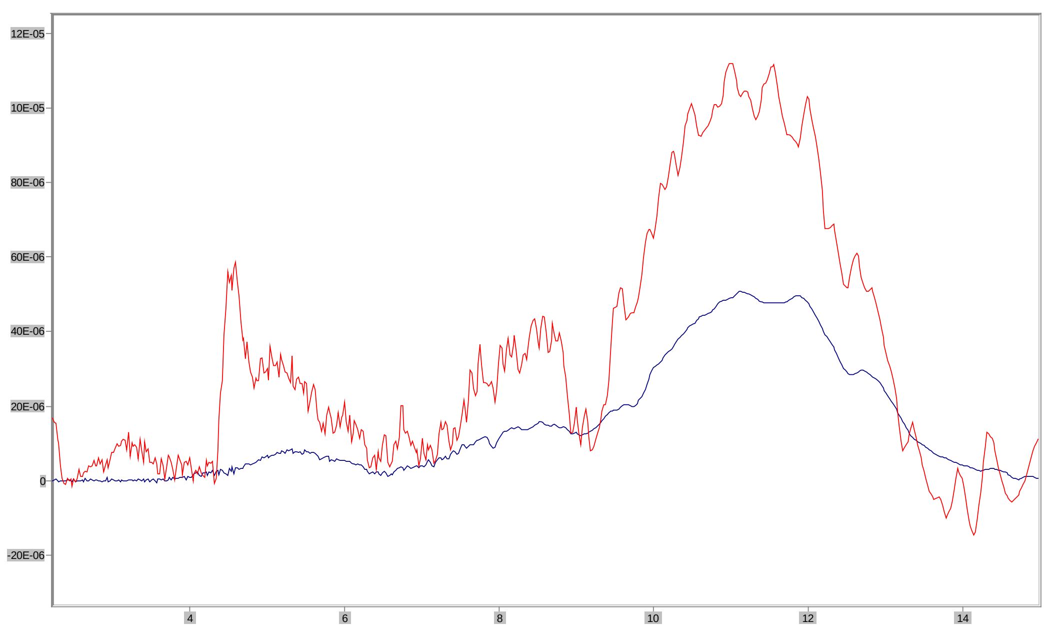
Arbitrary Y / Micrometers
Overlay Y-Zoom SCROLL
File # 2 = M222_77
7/2/97 12:02 PM Res=8cm-1
SINGLE file Split from micron.spc

Graph III-66: M206 Open Burn IR Spectra



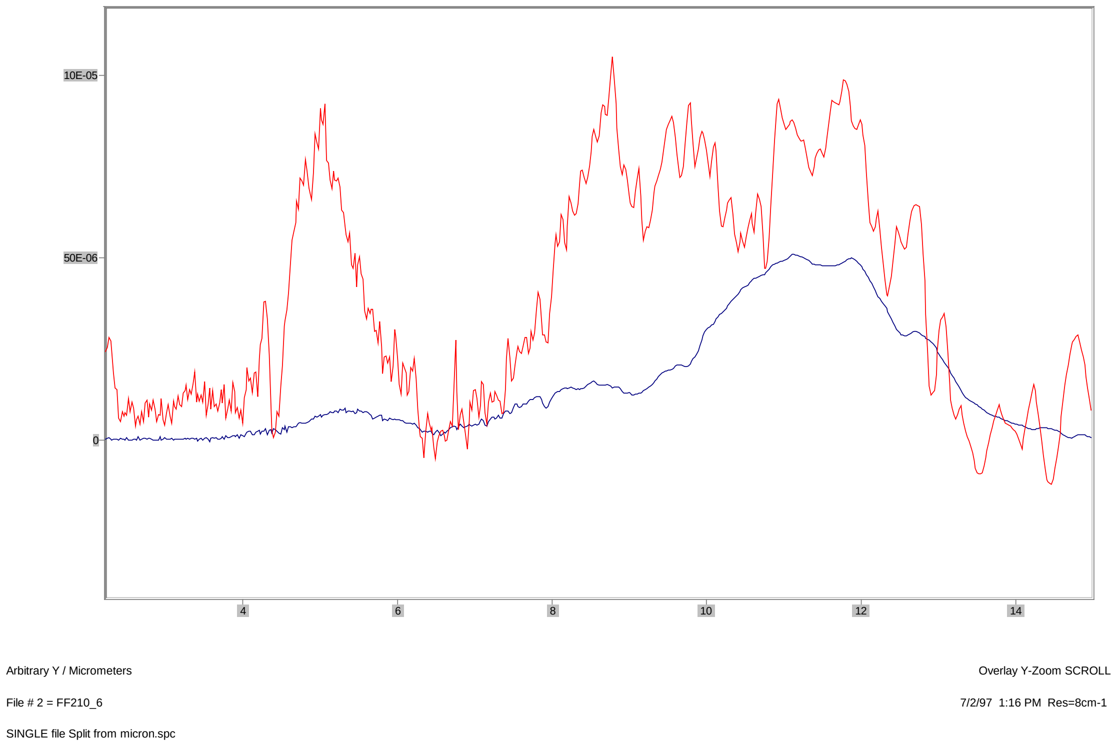
Arbitrary Y / Micrometers
Overlay Y-Zoom SCROLL
File # 2 = FF210_2
7/2/97 1:16 PM Res=8cm-1
SINGLE file Split from micron.spc

Graph III-67: First Fire Open Burn IR Spectra

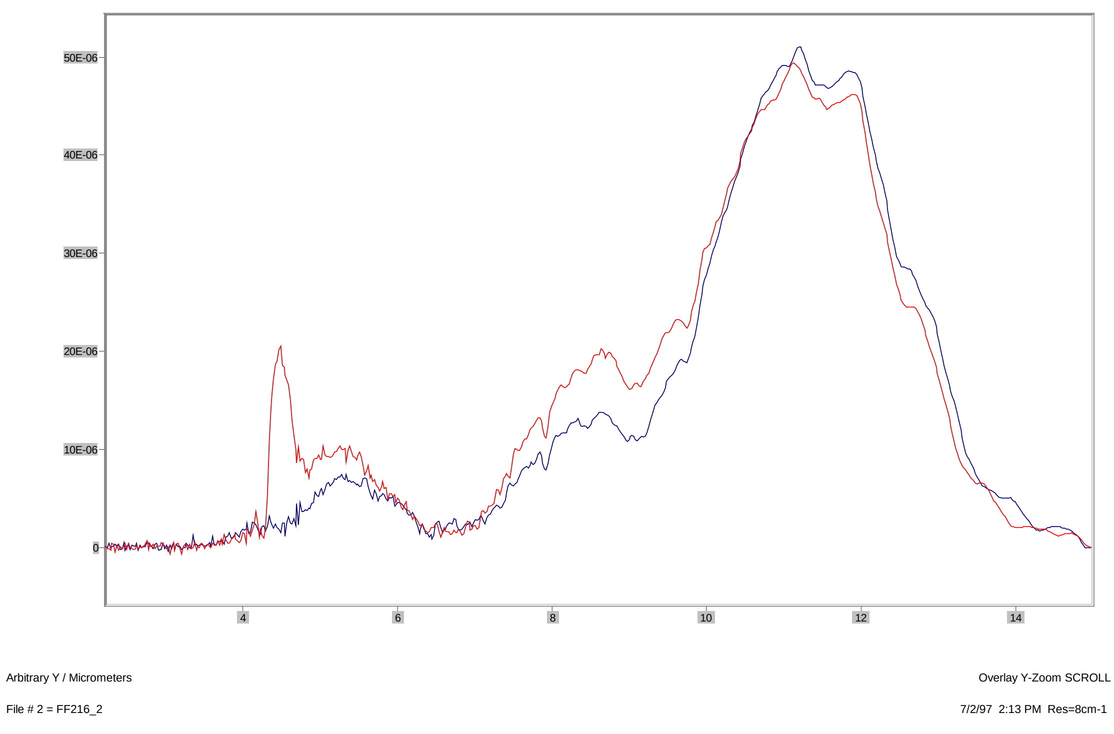


Arbitrary Y / Micrometers
Overlay Y-Zoom SCROLL
File # 2 = FF210_4
7/2/97 1:16 PM Res=8cm-1
SINGLE file Split from micron.spc

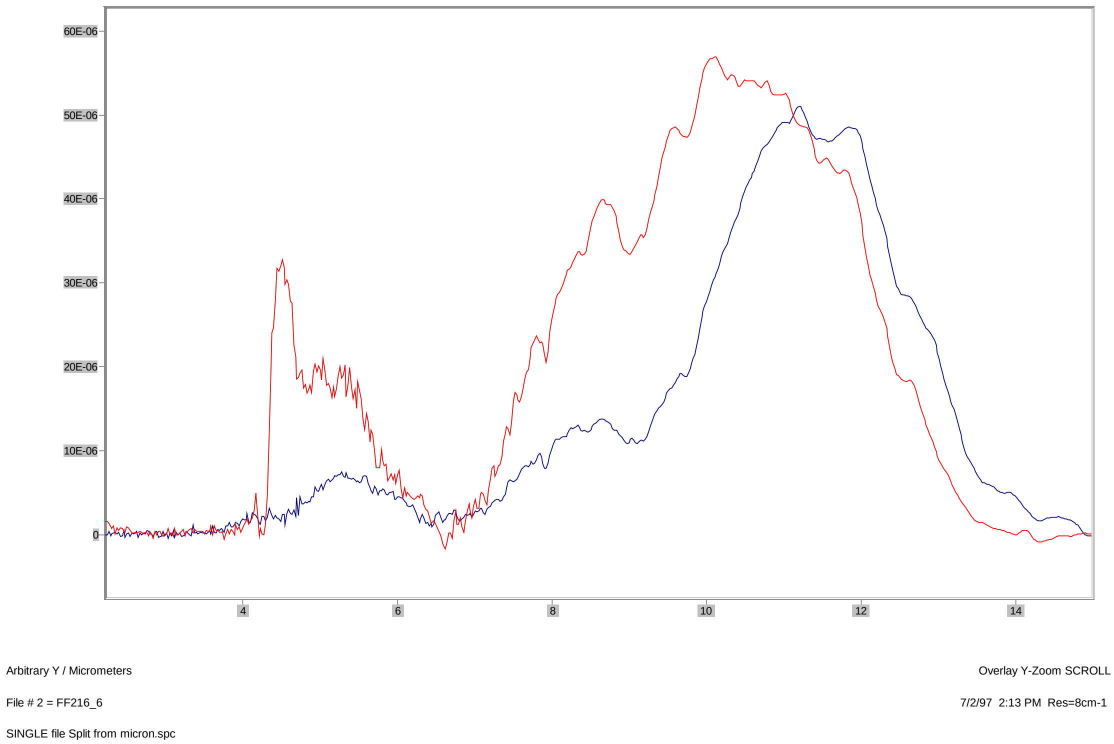
Graph III-68: First Fire Open Burn IR Spectra



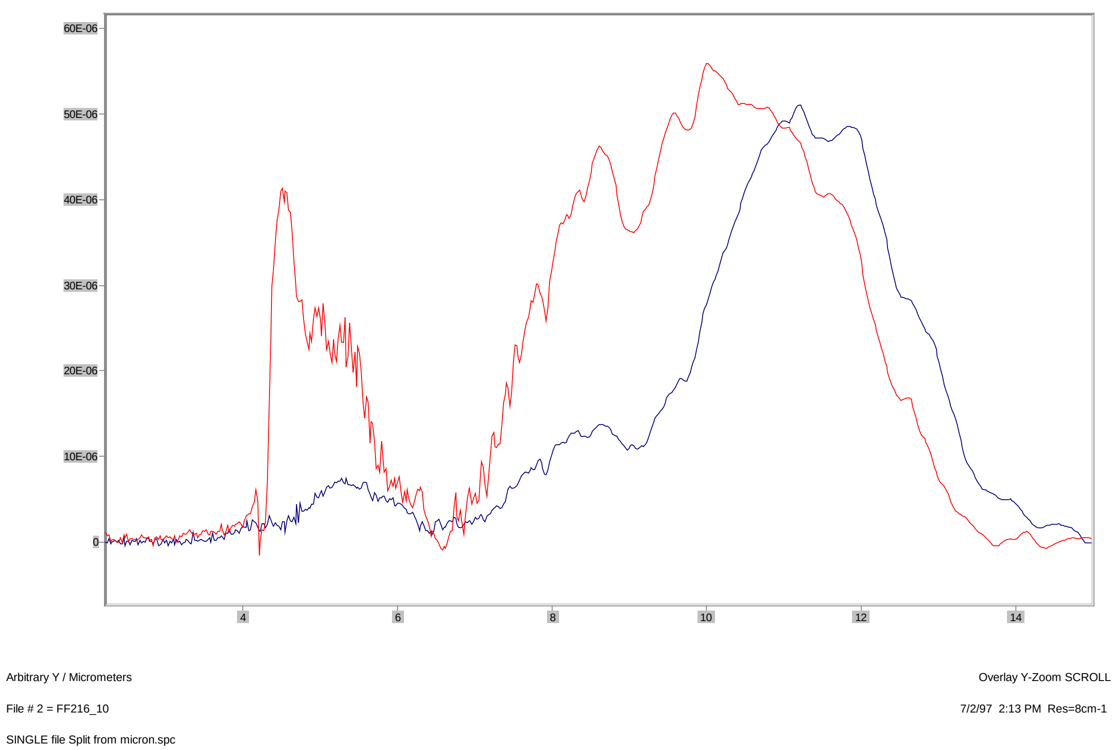
Graph III-69: First Fire Open Burn IR Spectra



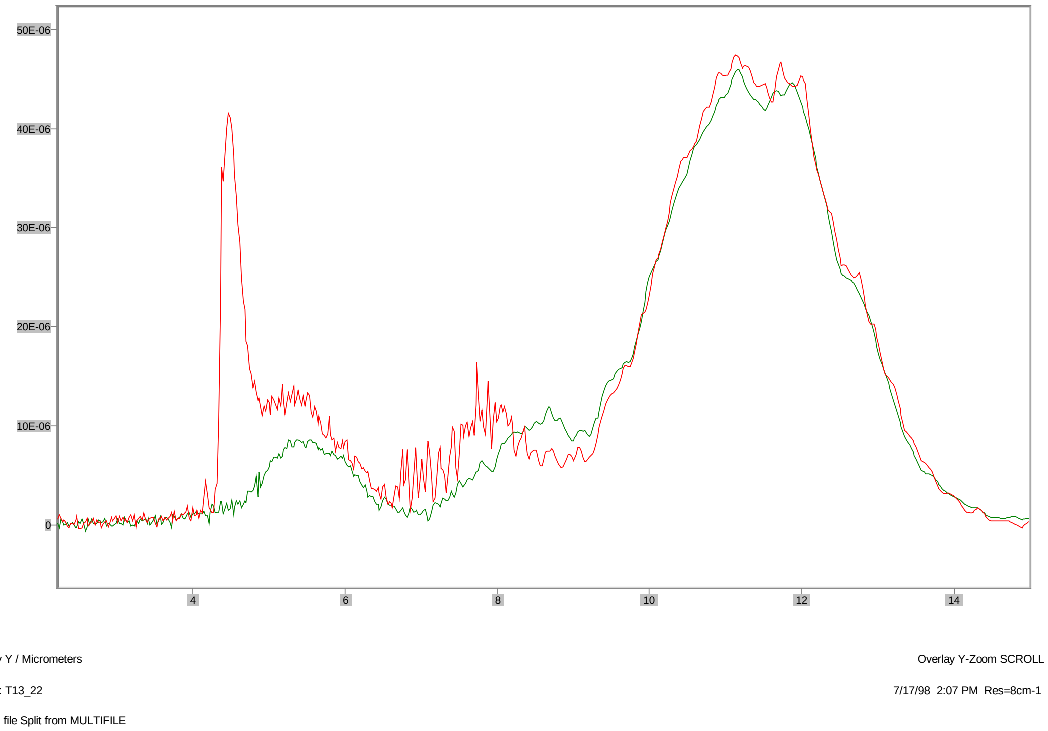
Graph III-70: First Fire Open Burn IR Spectra



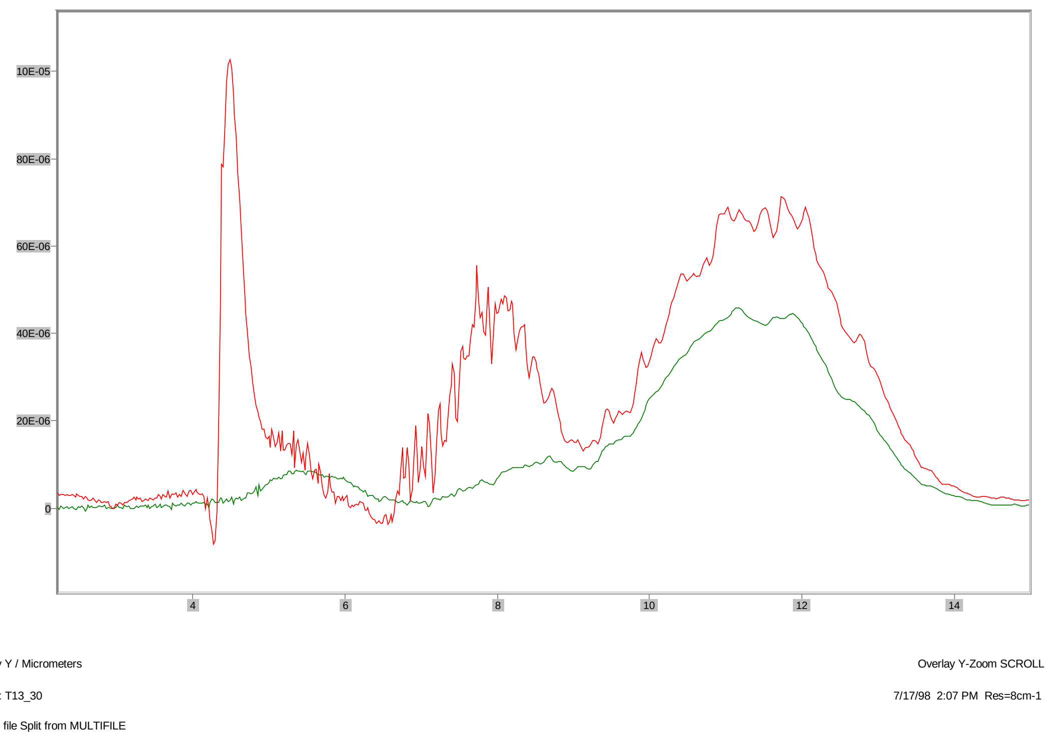
Graph III-71: First Fire Open Burn IR Spectra



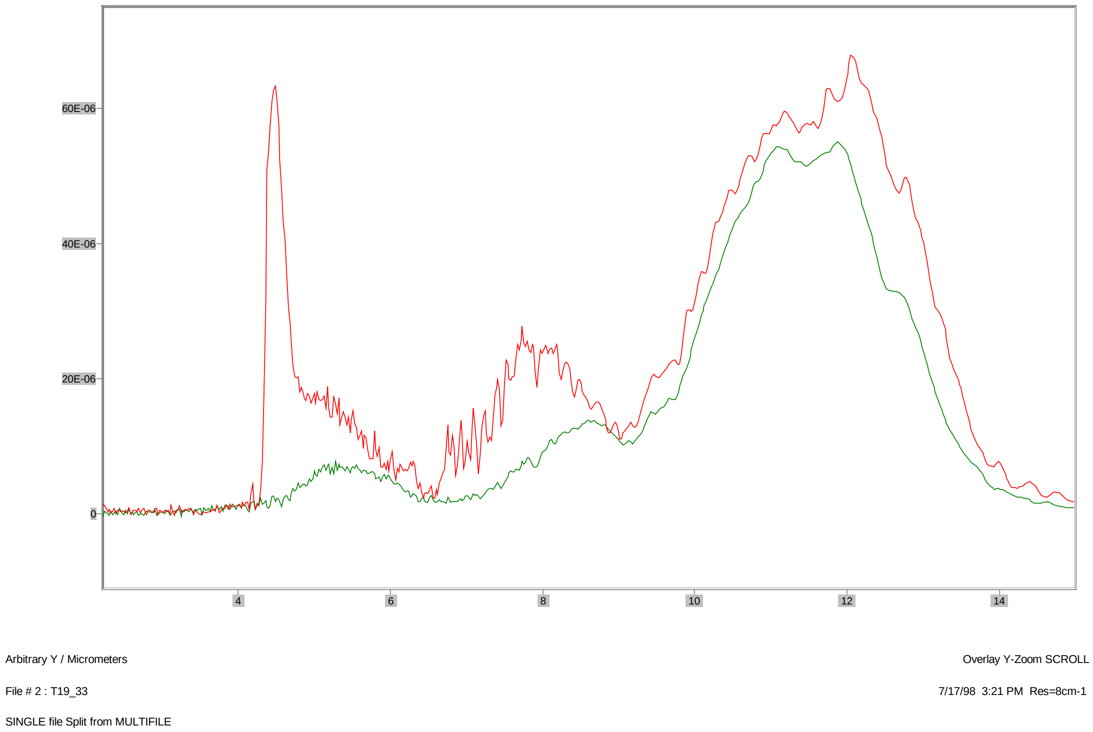
Graph III-72: First Fire Open Burn IR Spectra



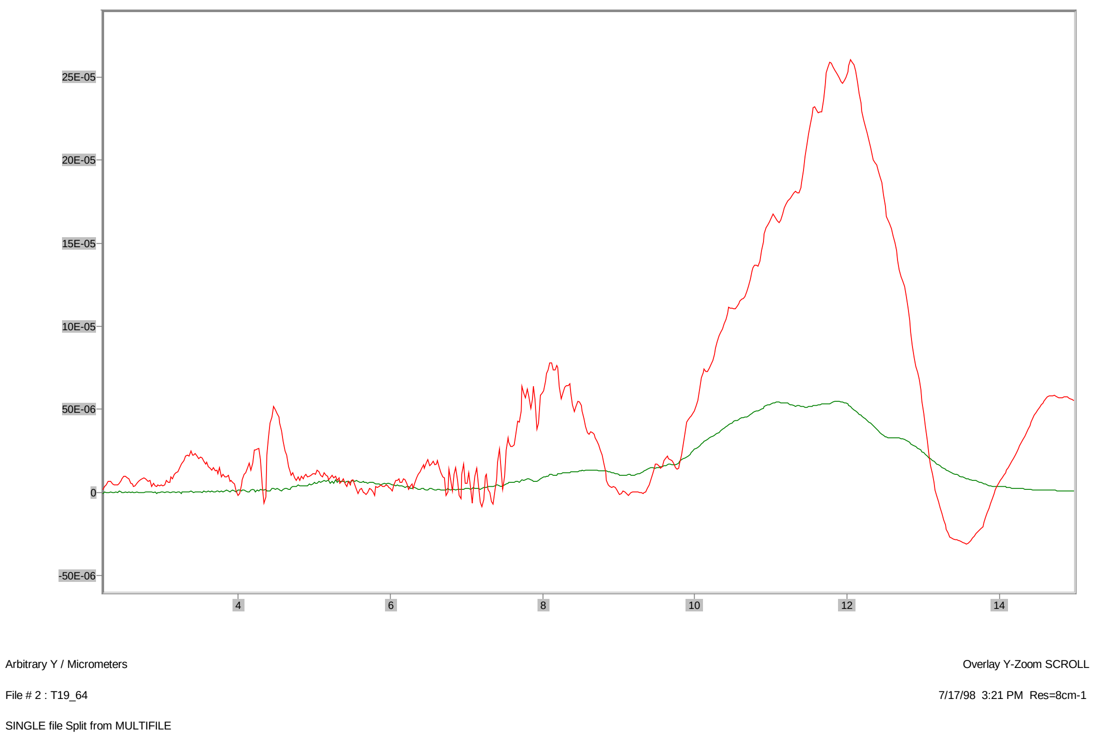
Graph III-73: UTP 19048 Open Burn IR Spectra



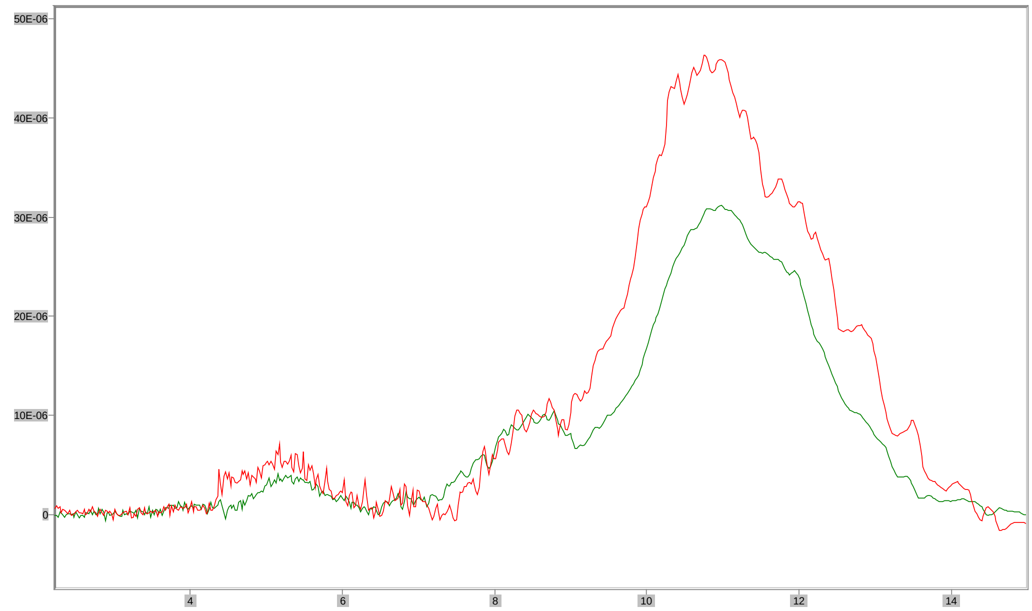
Graph III-74: UTP 19048 Open Burn IR Spectra



Graph III-75: UTP 19,360B Open Burn IR Spectra



Graph III-76: UTP 19,360B Open Burn IR Spectra



Arbitrary Y / Micrometers

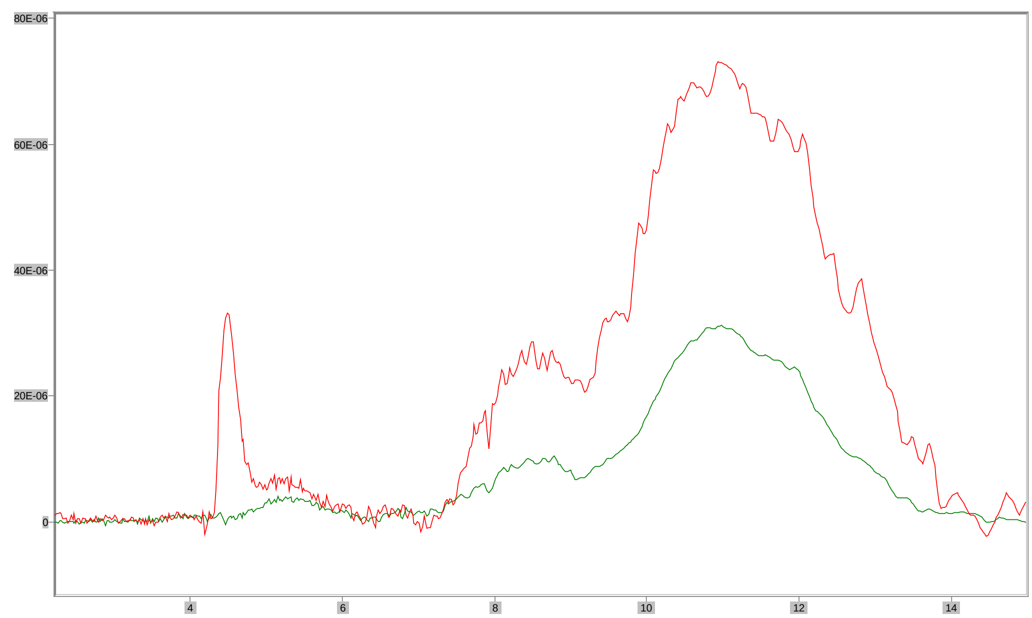
Overlay Y-Zoom SCROLL

File # 2 : T16_29

7/17/98 2:40 PM Res=8cm-1

SINGLE file Split from MULTIFILE

Graph III-77: UTP-24745D Open Burn IR Spectra



Arbitrary Y / Micrometers

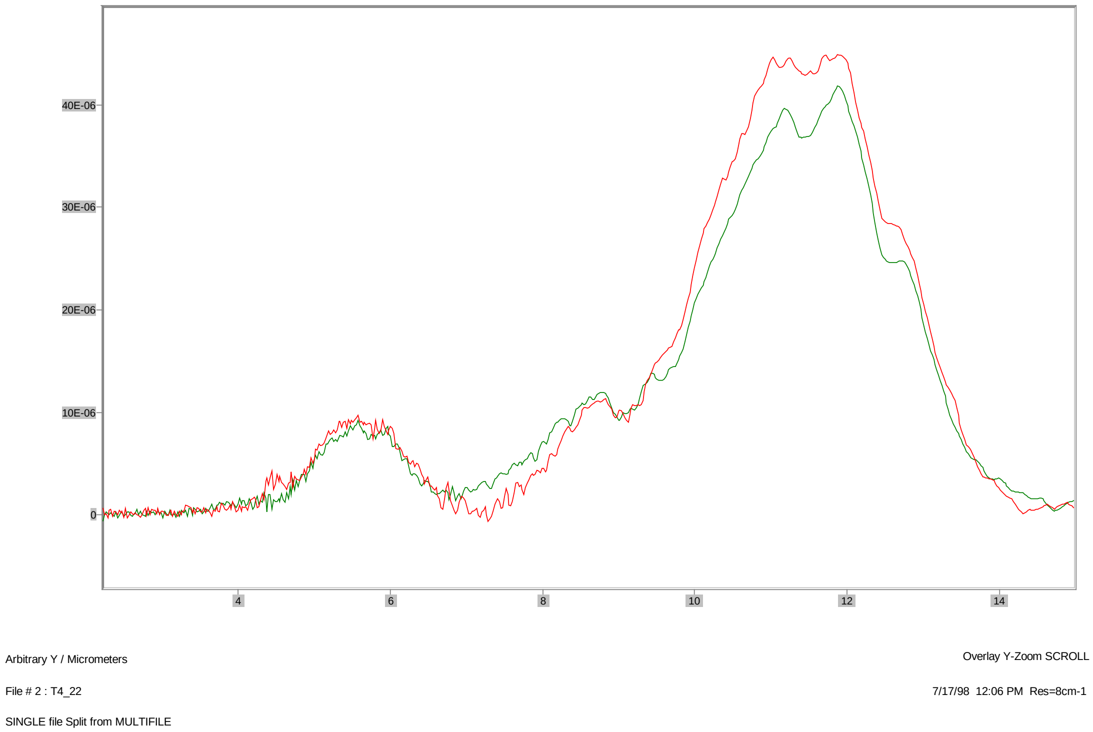
Overlay Y-Zoom SCROLL

File # 2 : T16_43

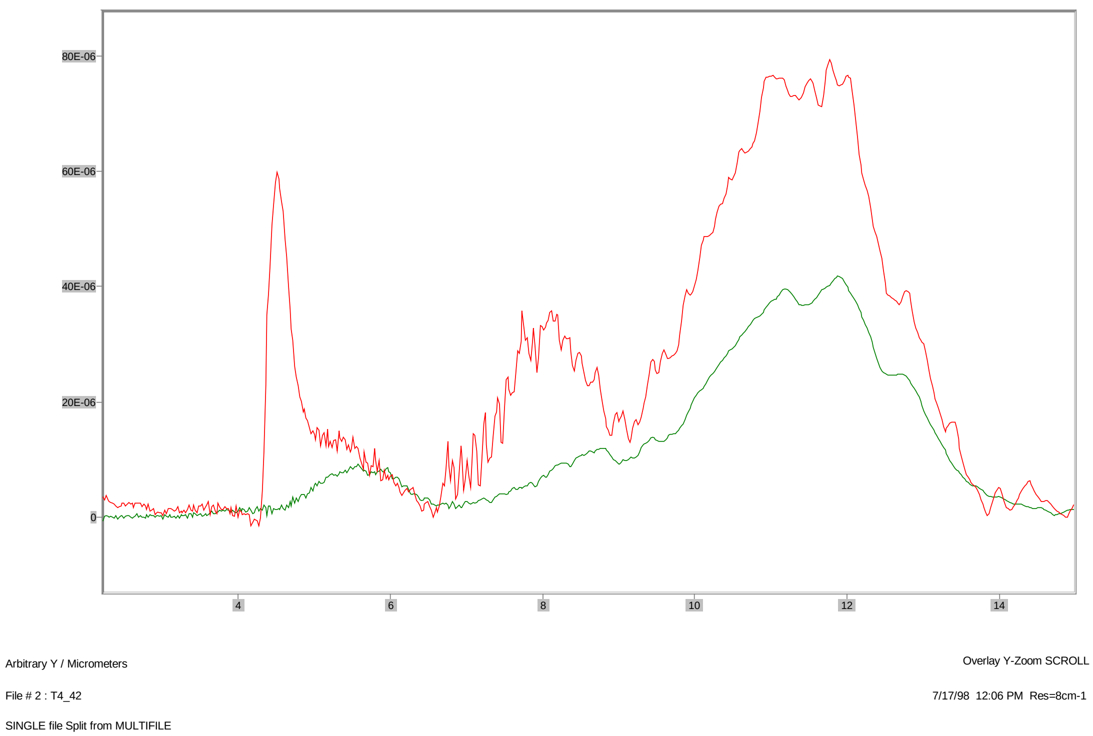
7/17/98 2:40 PM Res=8cm-1

SINGLE file Split from MULTIFILE

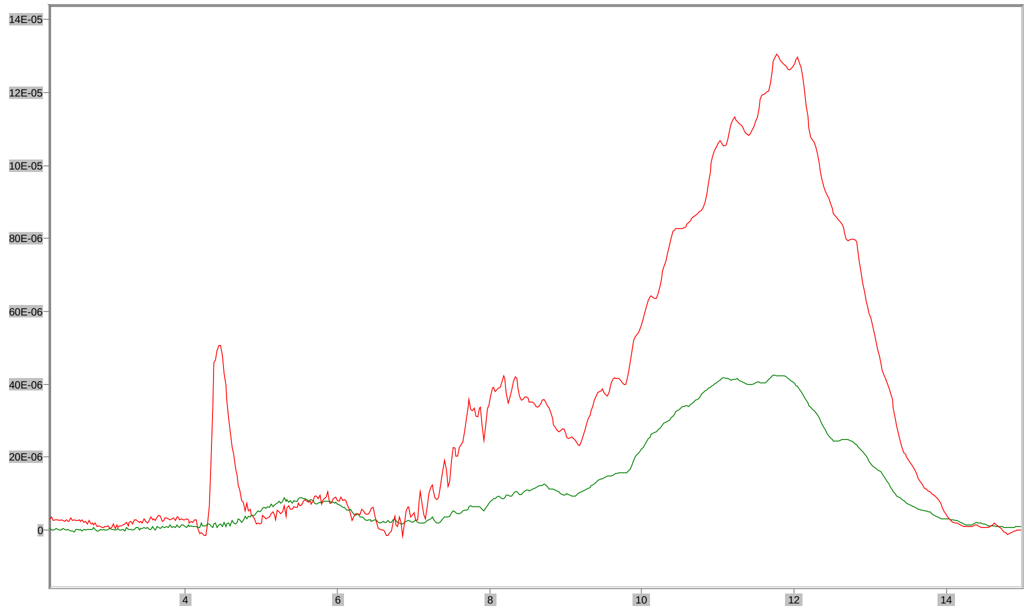
Graph III-78: UTP-24745D Open Burn IR Spectra



Graph III-79: UTP-25201C Open Burn IR Spectra



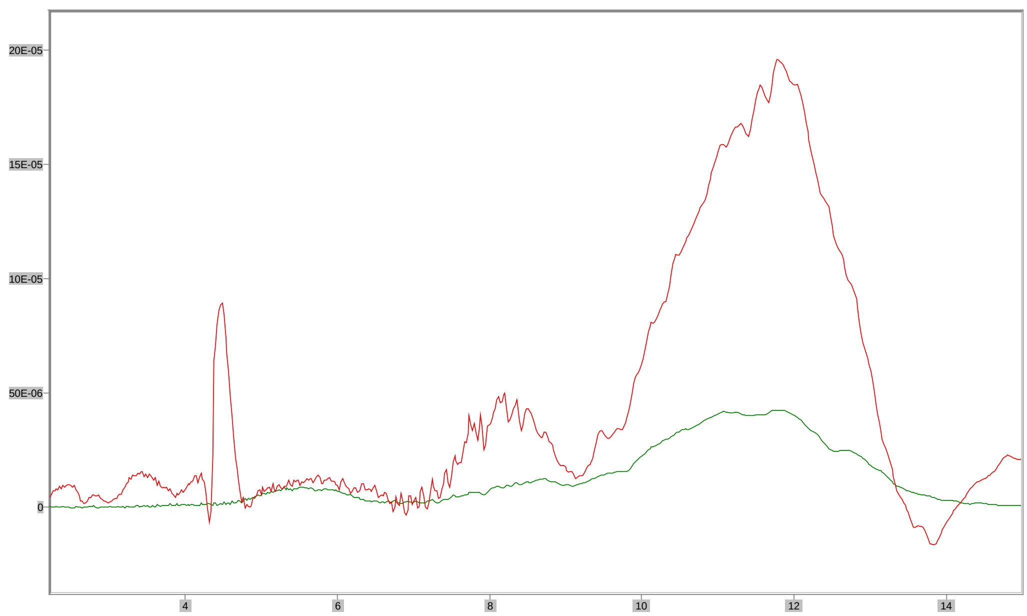
Graph III-80: UTP-25201C Open Burn IR Spectra



Arbitrary Y / Micrometers
File # 2 : T7_22
SINGLE file Split from MULTIFILE

Overlay Y-Zoom SCROLL
7/17/98 12:39 PM Res=8cm-1

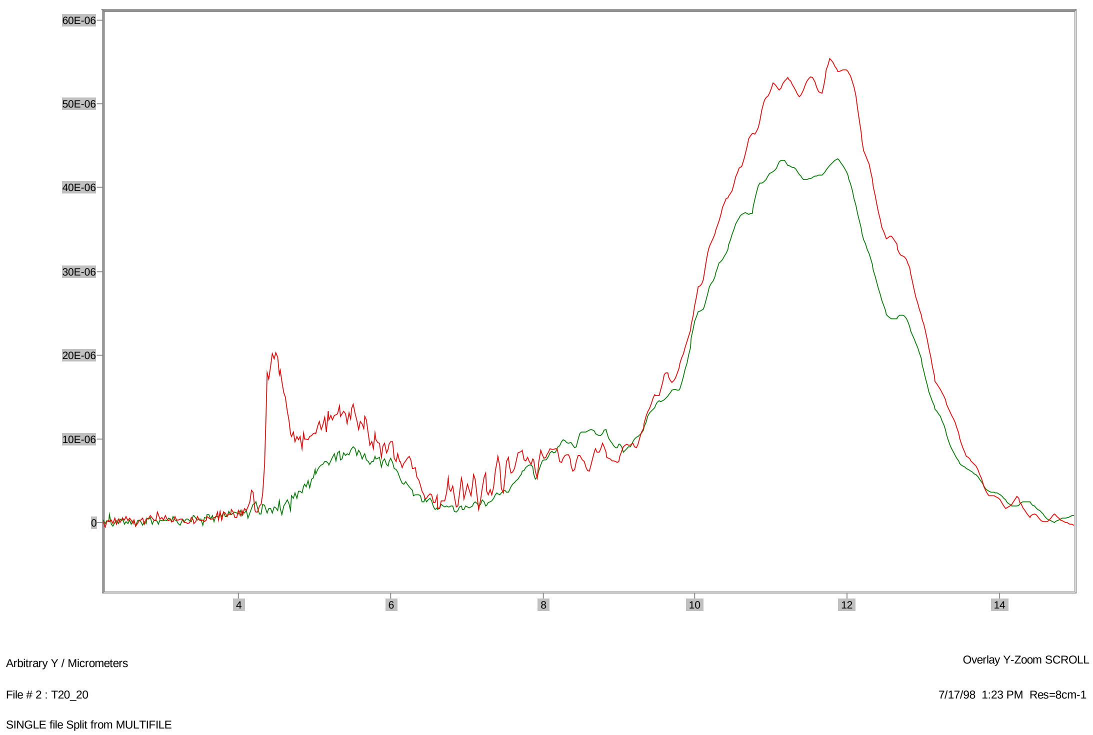
Graph III-81: UTP-3001B Open Burn IR Spectra



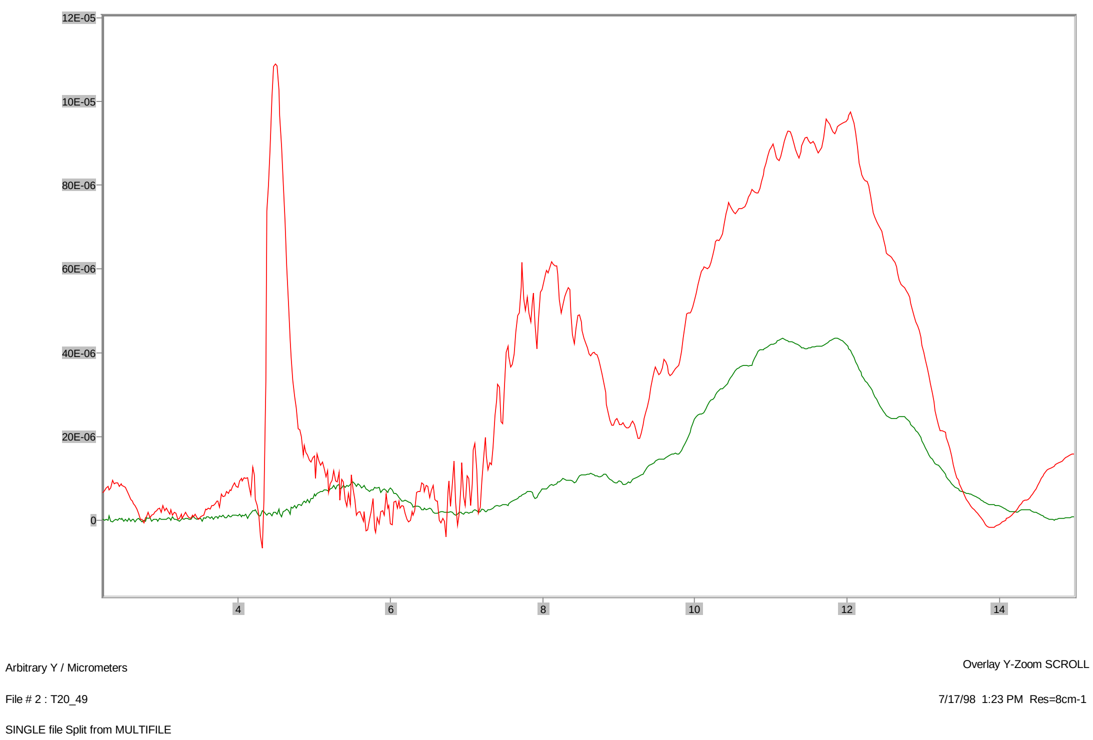
Arbitrary Y / Micrometers
File # 2 : T7_29
SINGLE file Split from MULTIFILE

Overlay Y-Zoom SCROLL
7/17/98 12:39 PM Res=8cm-1

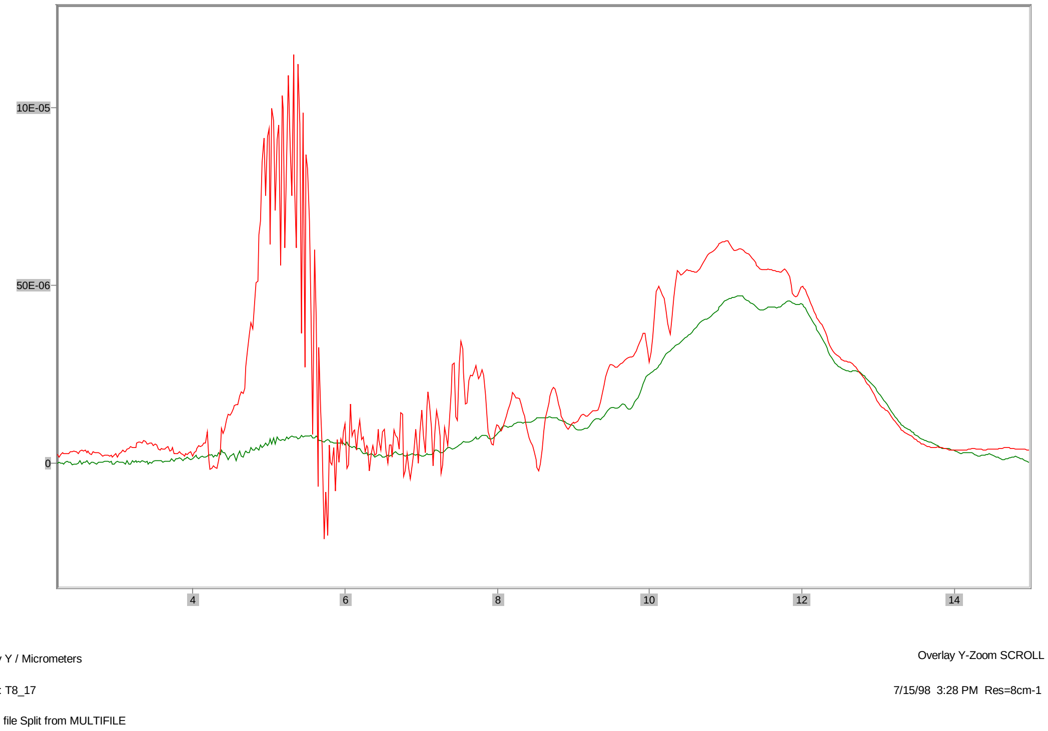
Graph III-82: UTP-3001B Open Burn IR Spectra



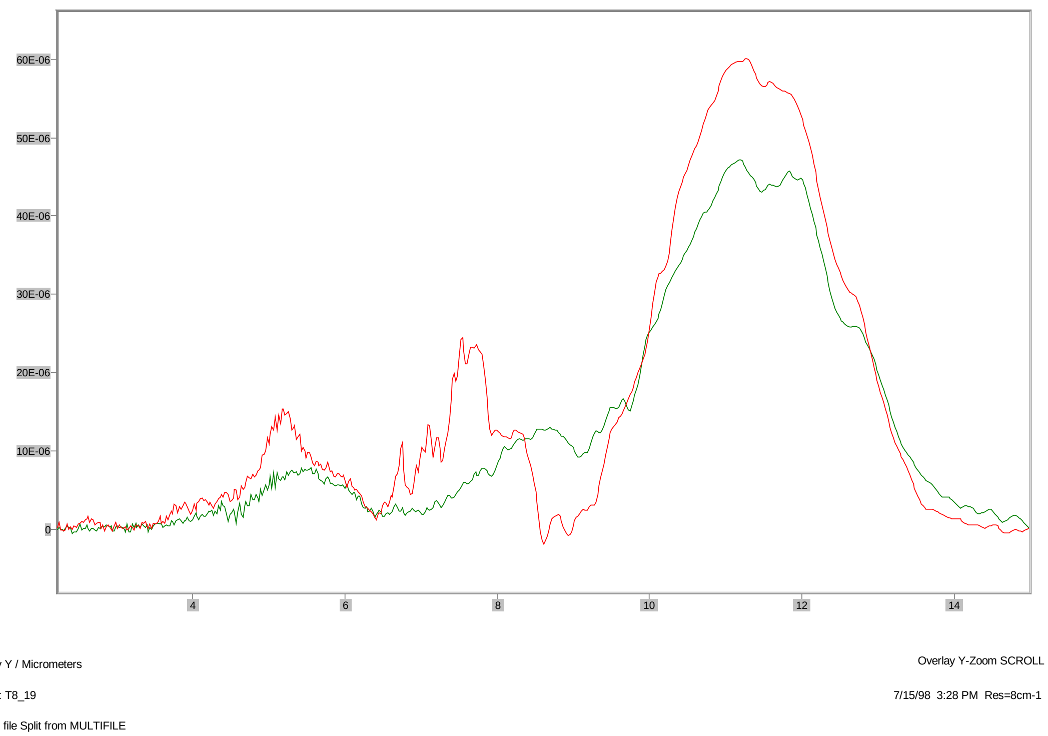
Graph III-83: UTP-31,500 Open Burn IR Spectra



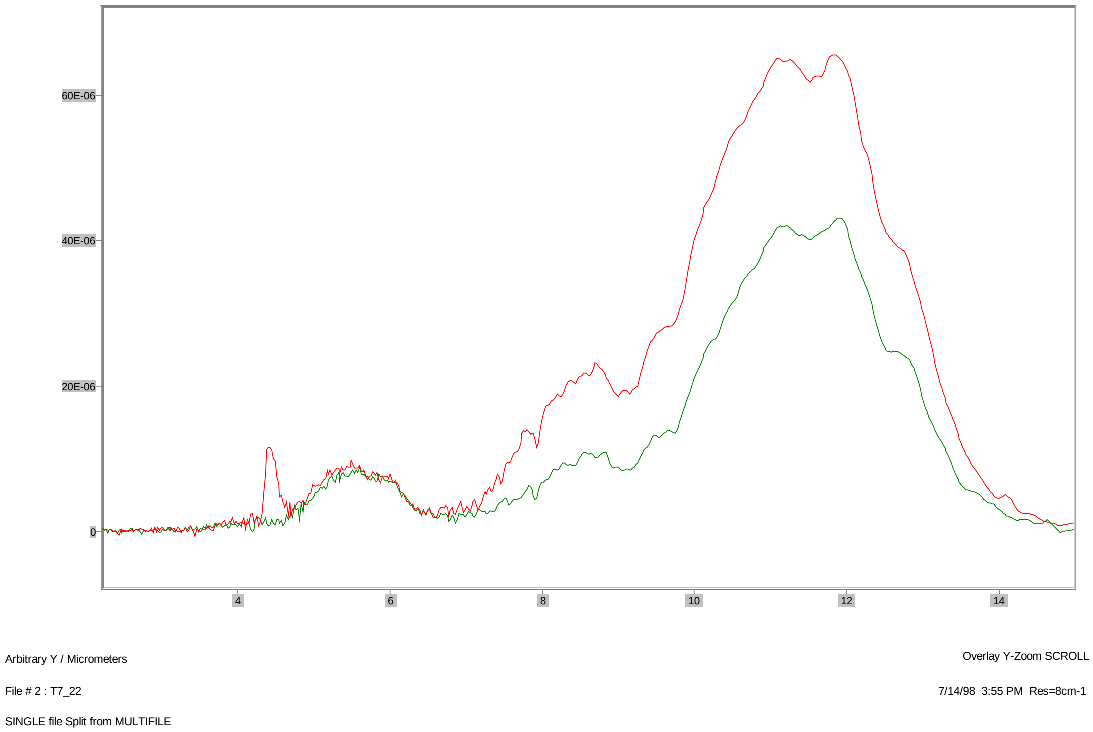
Graph III-84: UTP-31,500 Open Burn IR Spectra



Graph III-85: $BKNO_3$ Open Burn IR Spectra



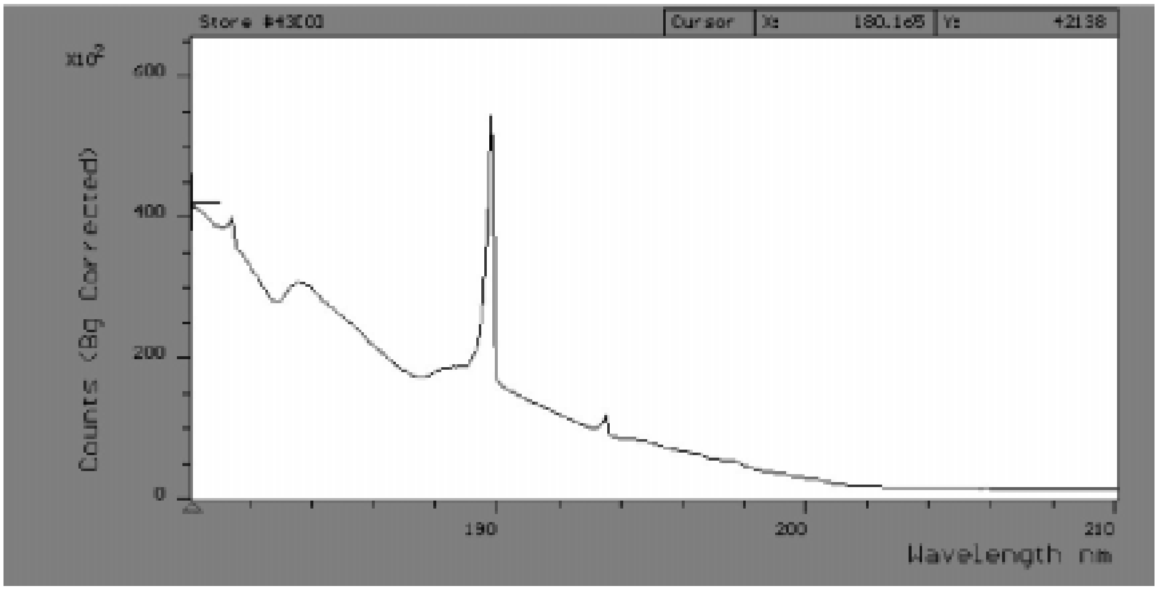
Graph III-86: $BKNO_3$ Open Burn IR Spectra



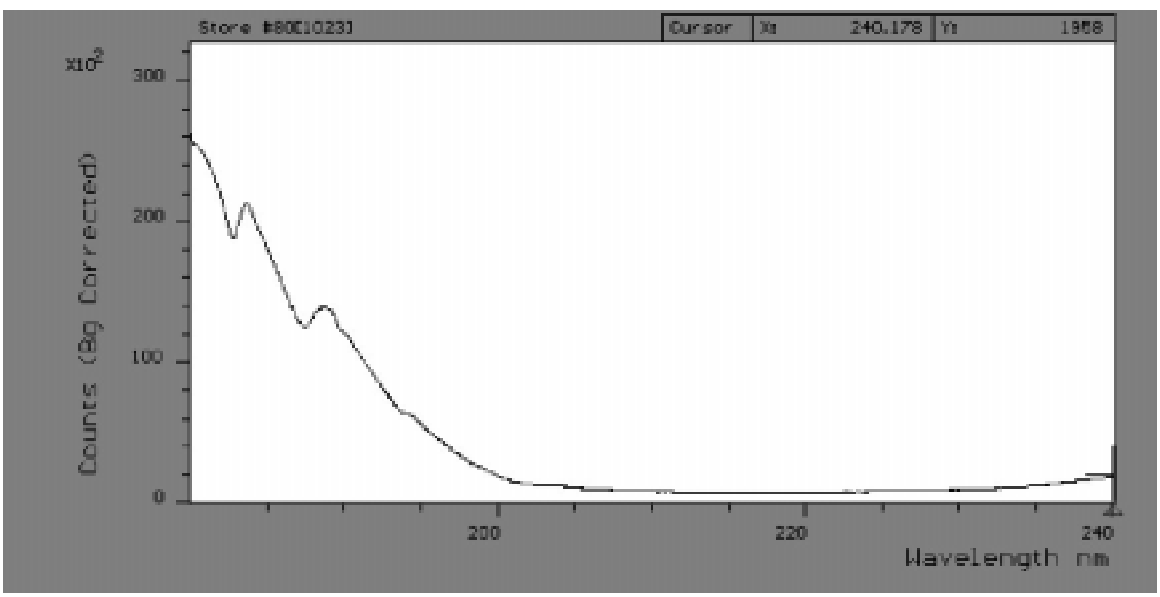
Graph III-87: MTV Open Burn IR Spectra

APPENDIX IV

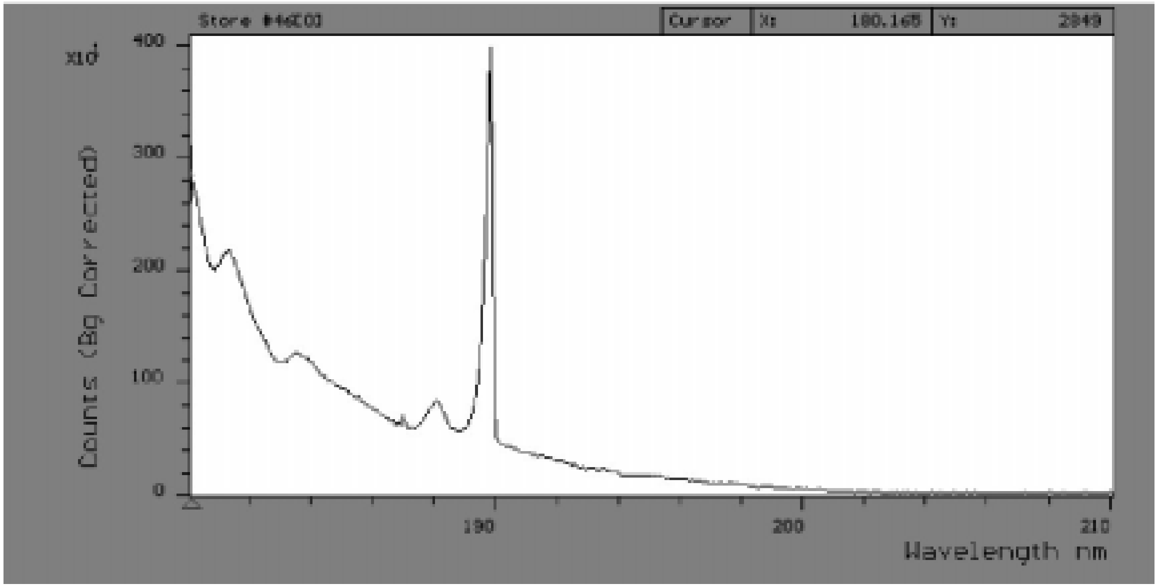
ULTRAVIOLET SPECTRAL DATA



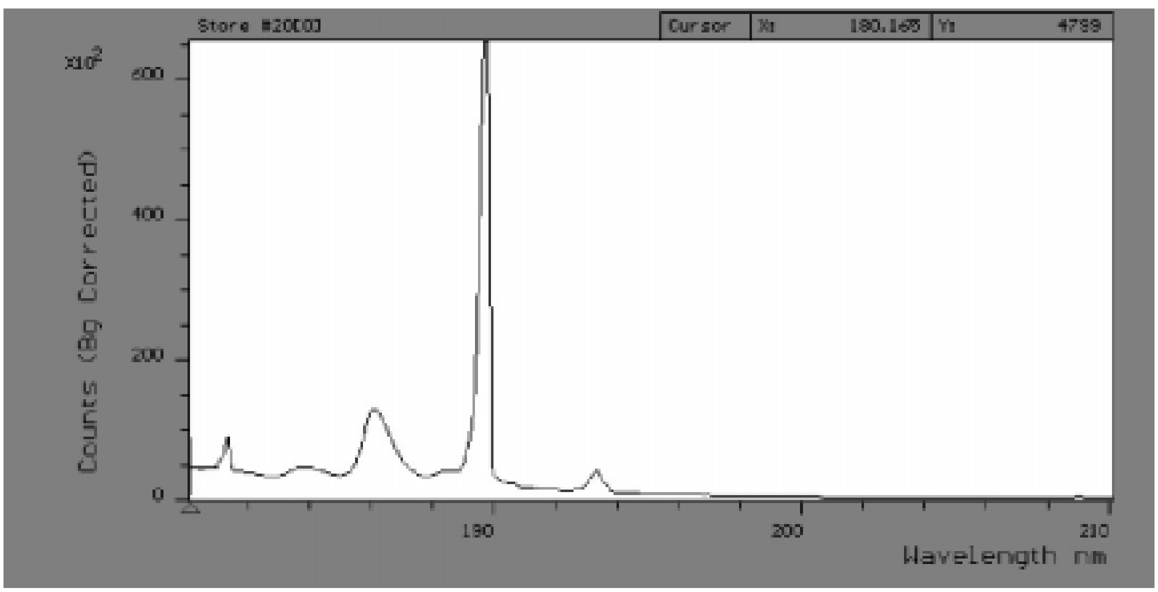
Graph IV-1: RS-40 Open Burn UV Spectra



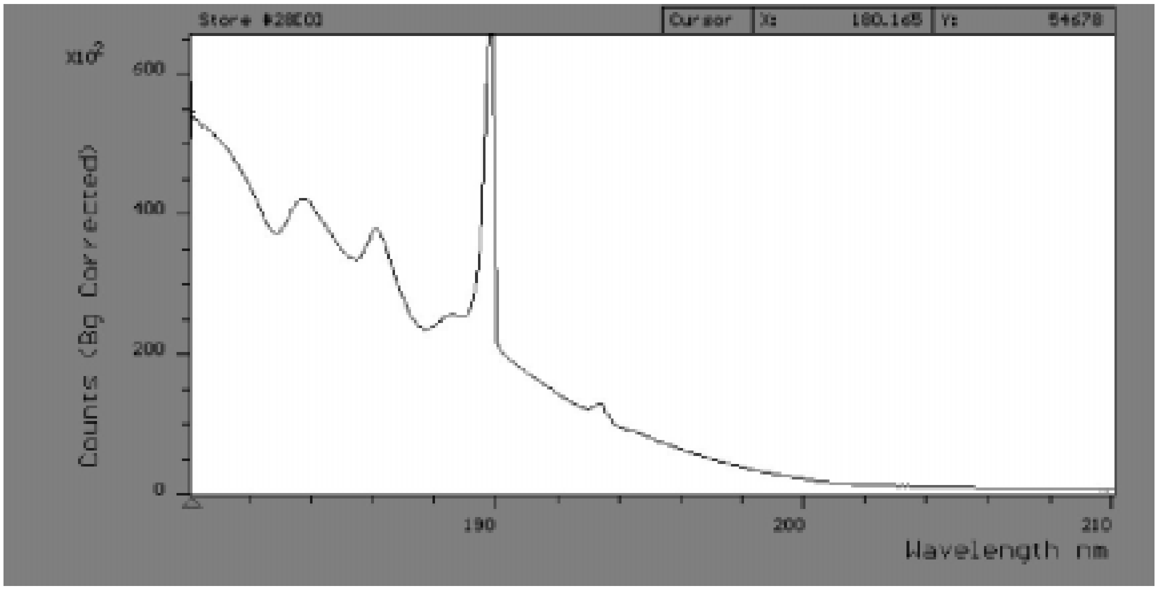
Graph IV-2: RS-41 Open Burn UV Spectra



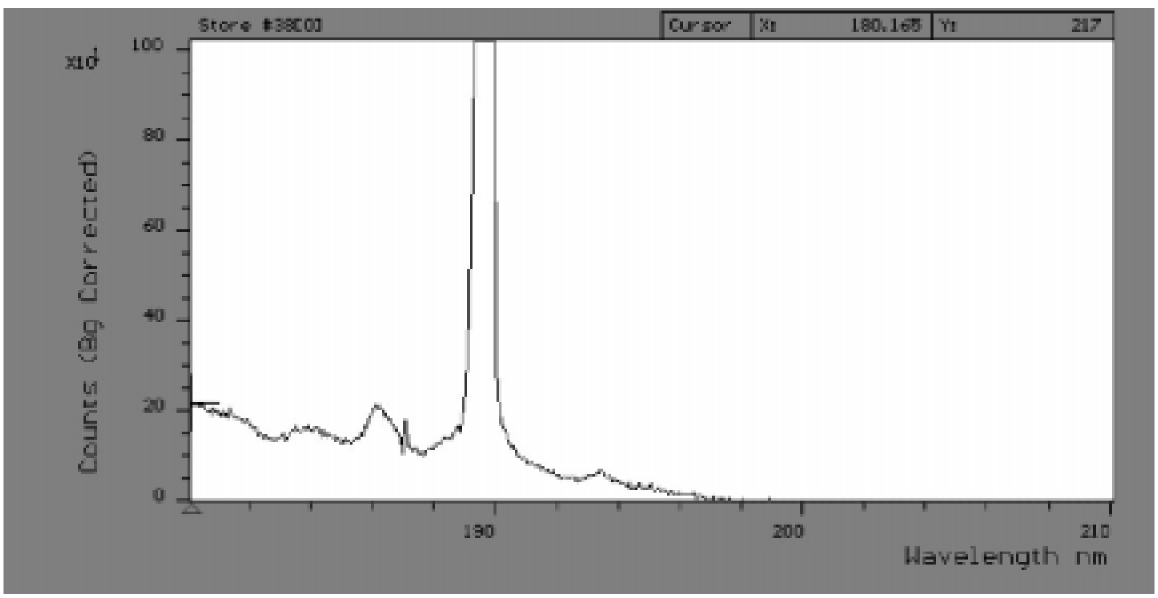
Graph IV-3: R-440 Open Burn UV Spectra



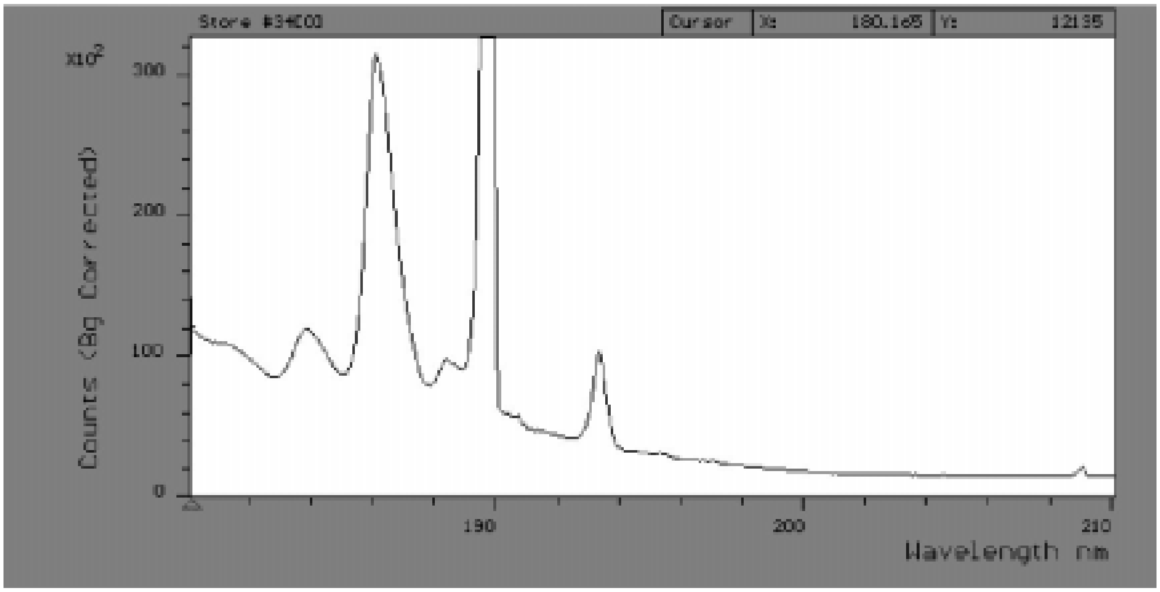
Graph IV-4: Hy-Skor 700X Open Burn UV Spectra



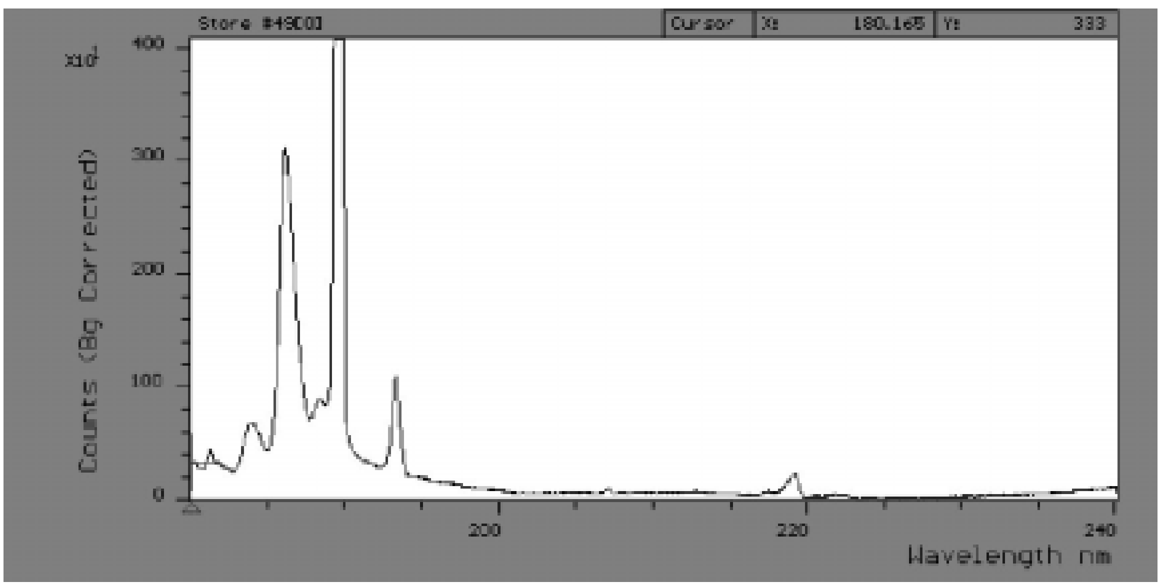
Graph IV-5: M14 Open Burn UV Spectra



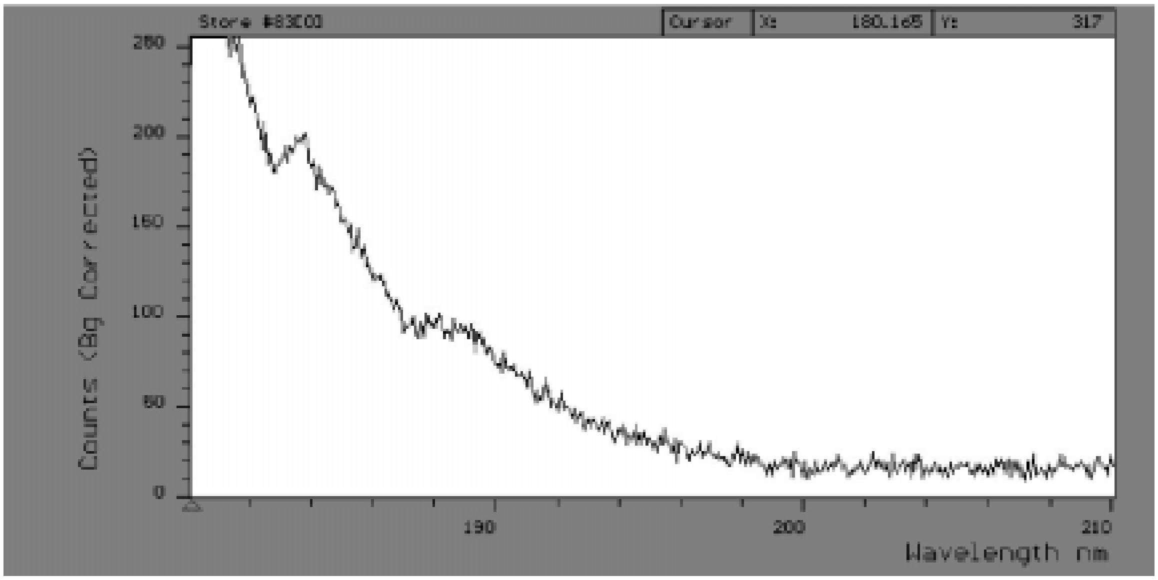
Graph IV-6: JA-2 Open Burn UV Spectra



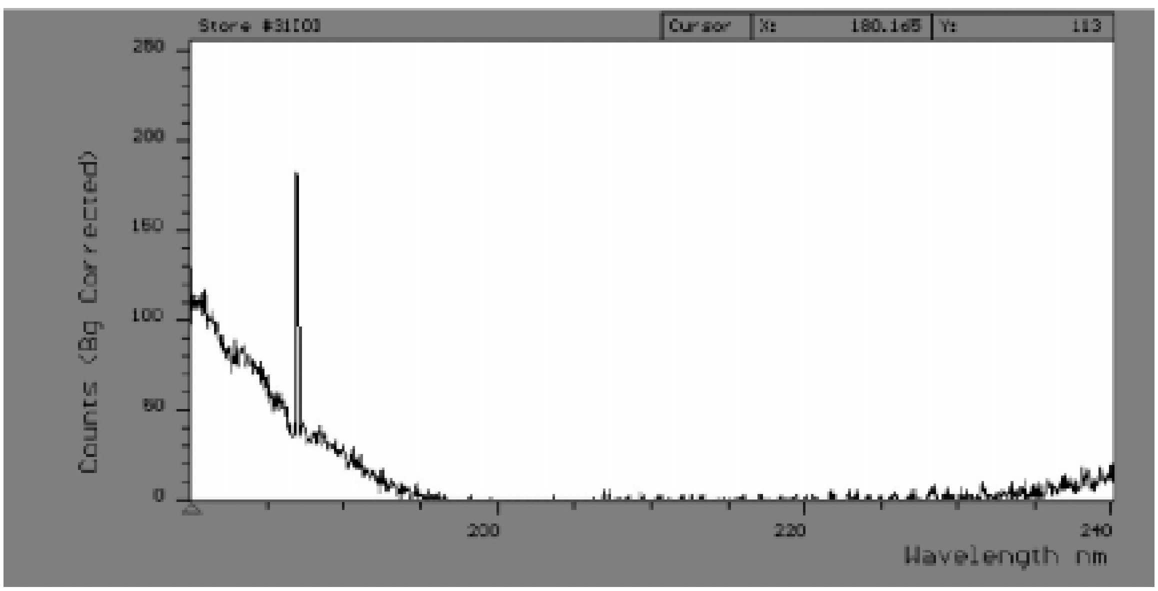
Graph IV-7: LKL Open Burn UV Spectra



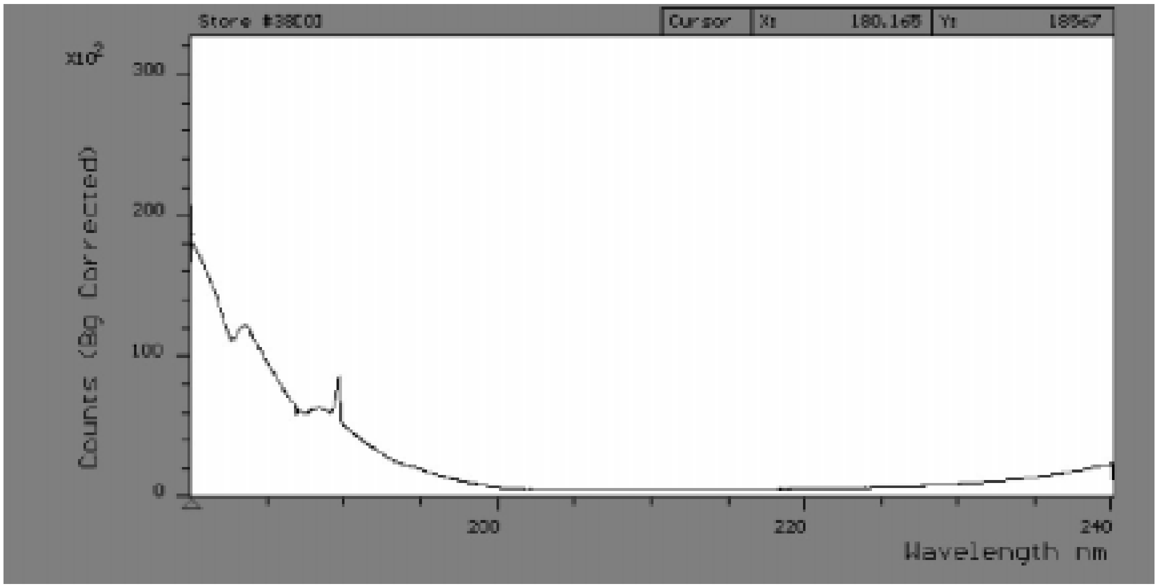
Graph IV-8: PBX-9501 Open Burn UV Spectra



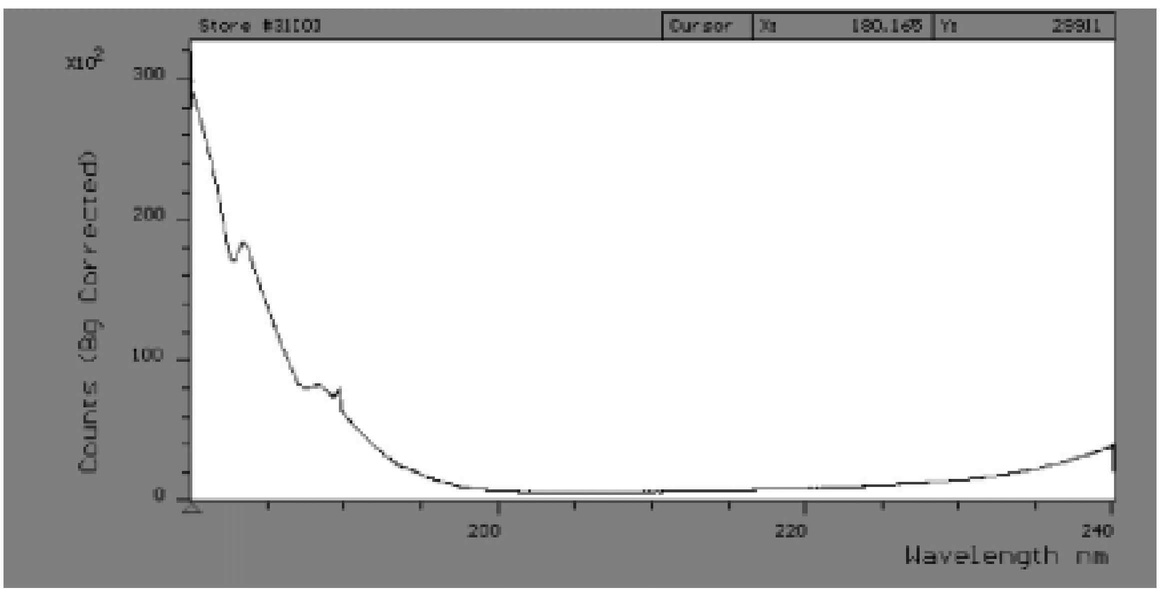
Graph IV-9: MK-25 Open Burn UV Spectra



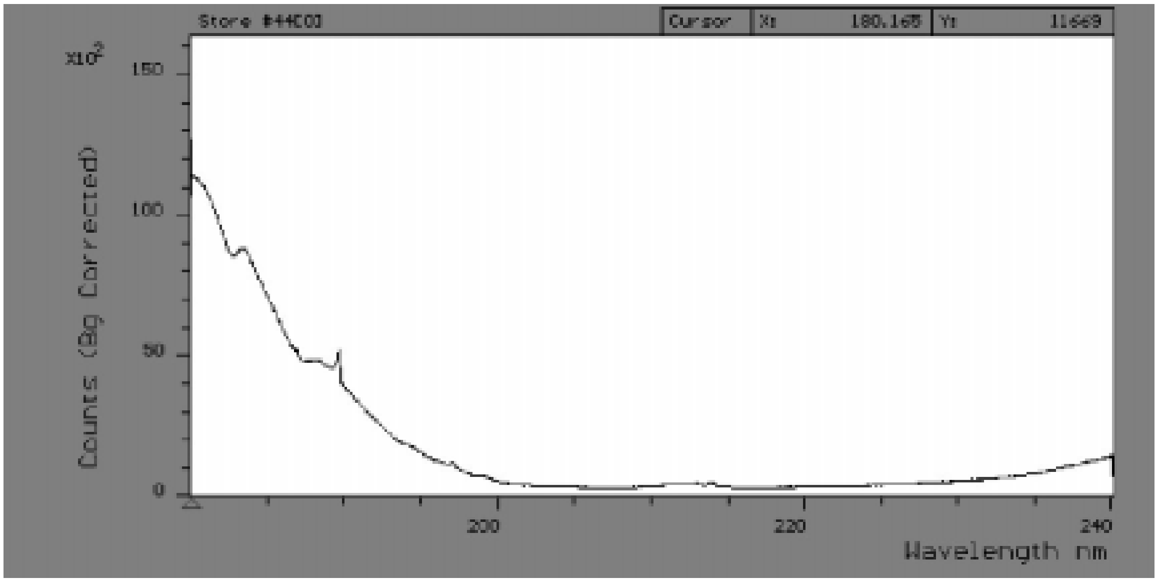
Graph IV-10: Red Lead Open Burn UV Spectra



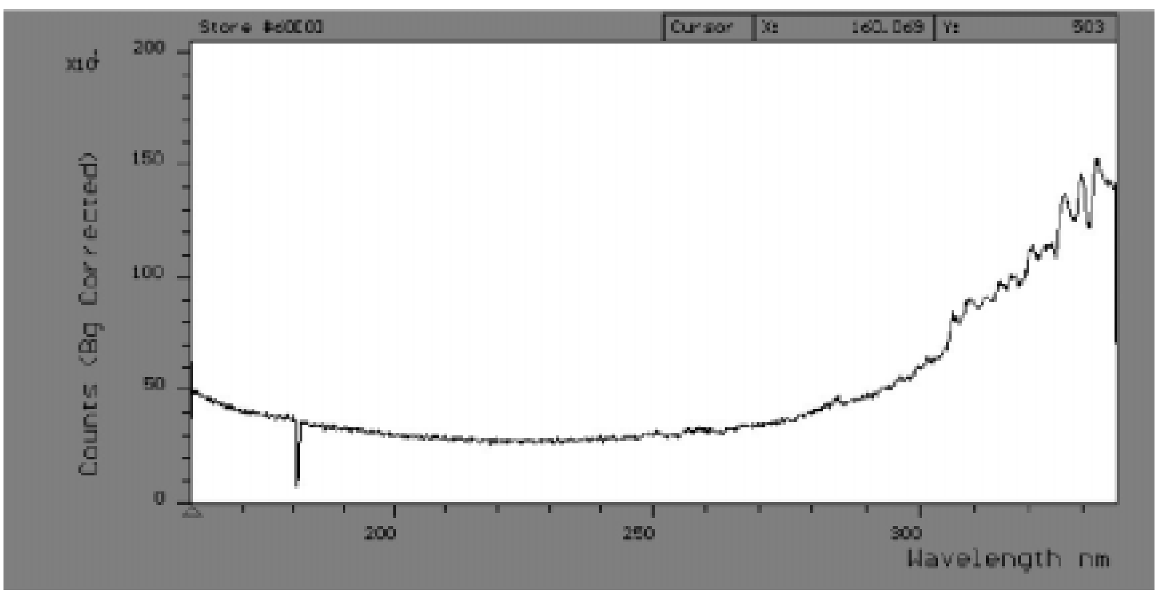
Graph IV-11: Green Smoke Open Burn UV Spectra



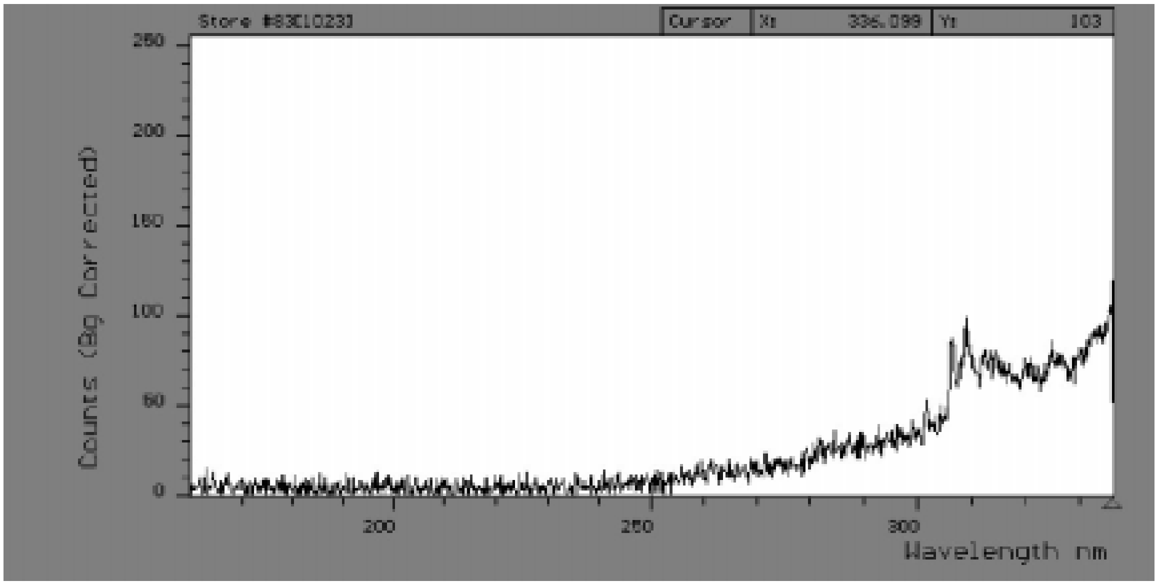
Graph IV-12: Yellow Smoke Open Burn UV Spectra



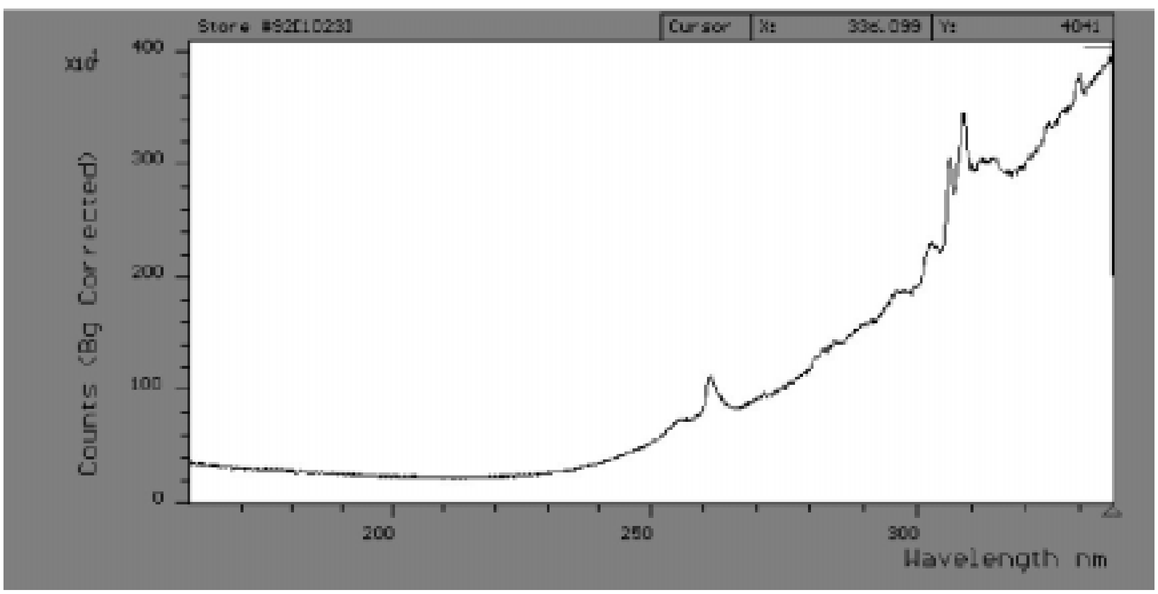
Graph IV-13: M206 Open Burn UV Spectra



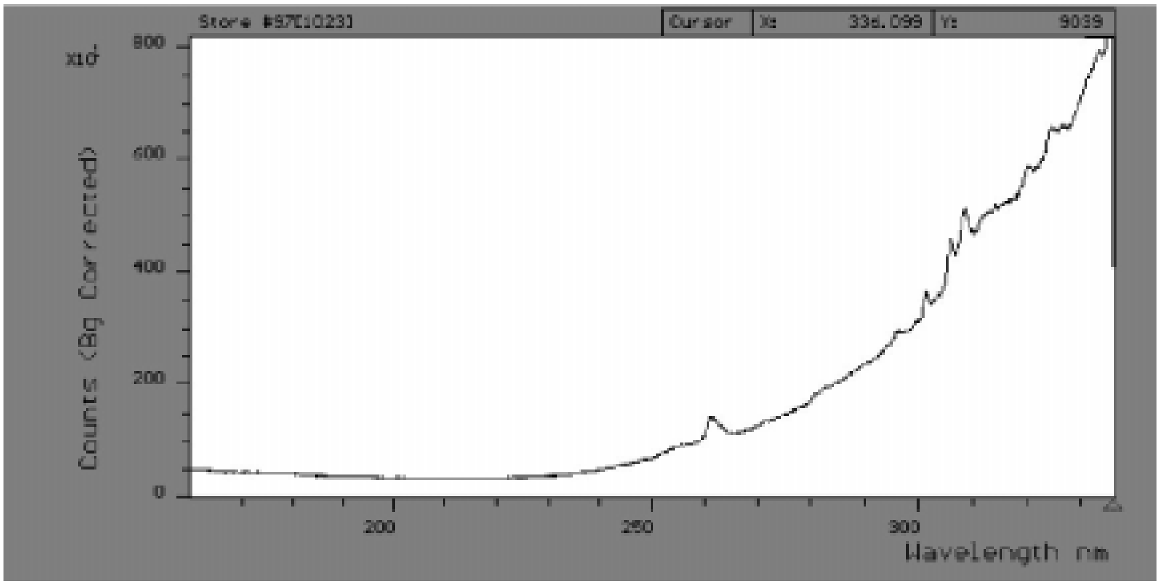
Graph IV-14: First Fire Open Burn UV Spectra



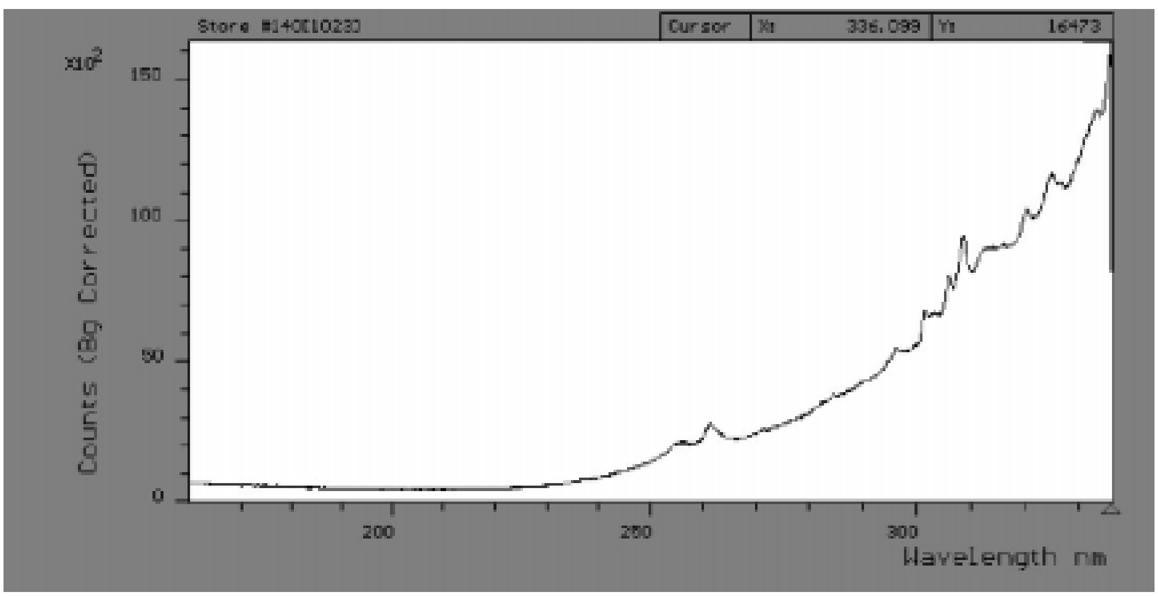
Graph IV-15: UTP 19048 Open Burn UV Spectra



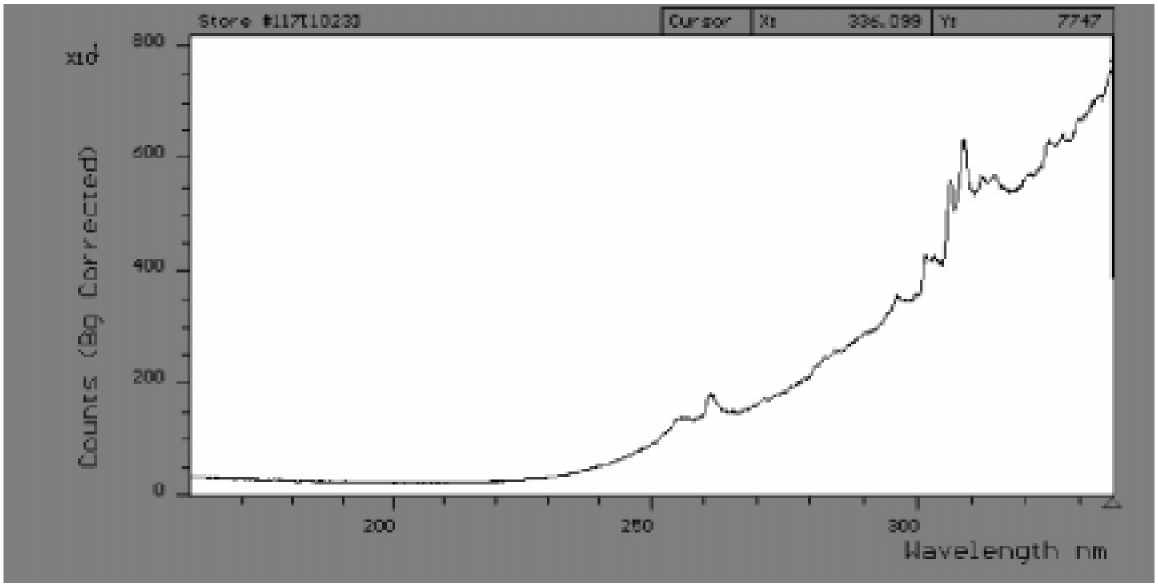
Graph IV-16: UTP-19,360B Open Burn UV Spectra



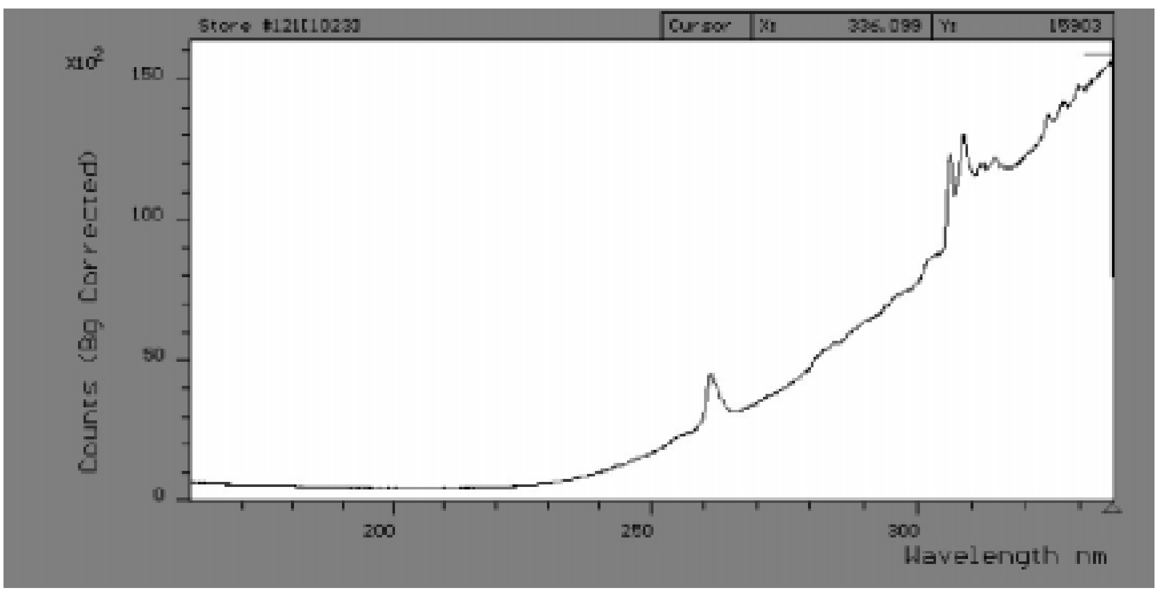
Graph IV-17: UTP-24745D Open Burn UV Spectra



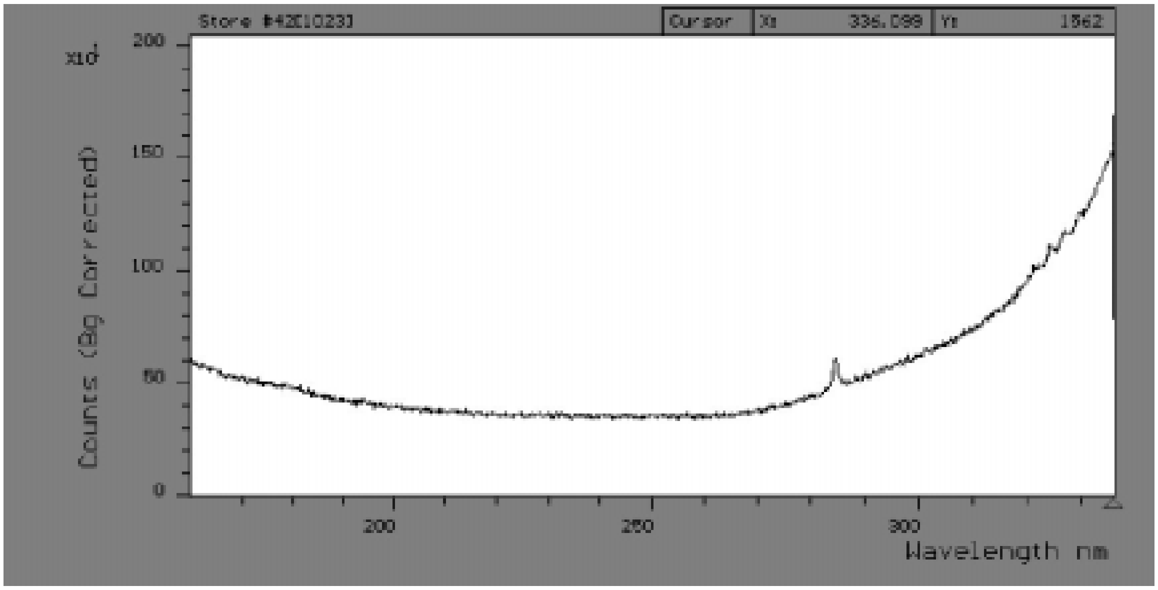
Graph IV-18: UTP-25201C Open Burn UV Spectra



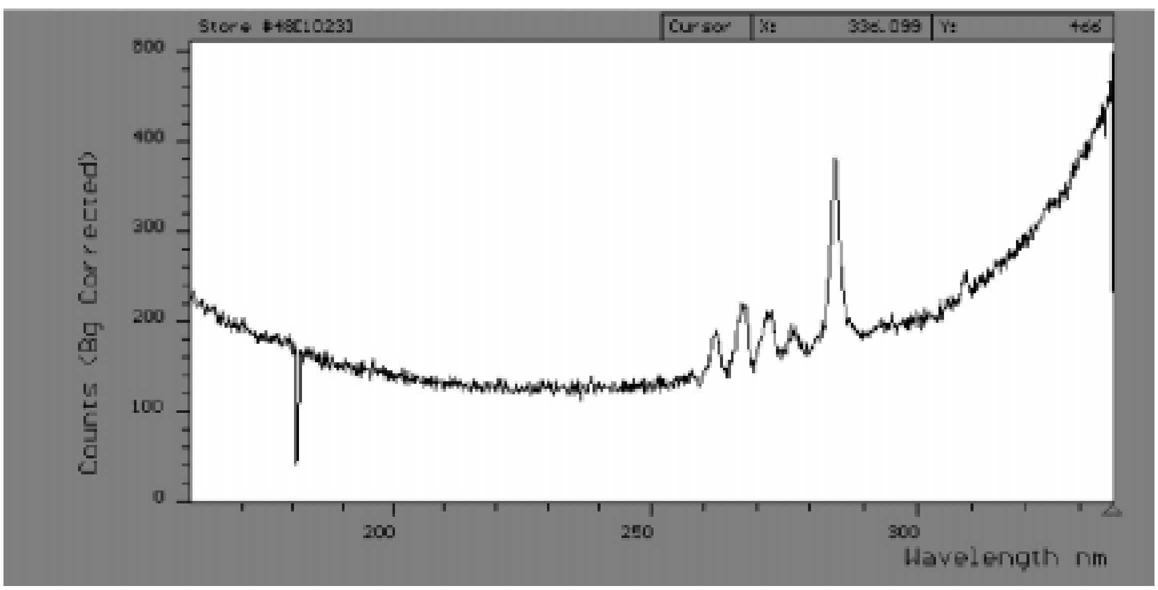
Graph IV-19: UTP-3001B Open Burn UV Spectra



Graph IV-20: UTP-31,500 Open Burn UV Spectra



Graph IV-21: $BKNO_3$ Open Burn UV Spectra



Graph IV-22: MTV Open Burn UV Spectra